



Cold-Flow Testing of a Proposed Integrated Center-Body Diffuser/Steam Blocker Concept for Plum Brook Station's B-2 Test Facility

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Abstract

The center-body diffuser (CBD) steam blocker (SB) system is a concept that incorporates a set of secondary drive nozzles into the envelope of a CBD, such that both nozzle systems (i.e., the rocket engine and the steam blocking nozzles) utilize the same supersonic diffuser, and will operate either singularly or concurrently. In this manner, the SB performs as an exhaust system stage when the rocket engine is not operating, and virtually eliminates discharge flow on rocket engine shutdown.

A 2.25-percent scale model of a proposed SB integrated into a diffuser for the Plum Brook B-2 facility was constructed and cold-flow tested for the purpose of evaluating performance characteristics of various design options. These specific design options addressed secondary drive nozzle design (method of steam injection), secondary drive nozzle location relative to CBD throat, and center-body throat length to diameter (L/D) ratios.

The objective of the test program is to identify the desired configuration to carry forward should the next phase of design proceed. The tested scale model can provide data for various pressure ratios; however, its design is based on a proposed B-2 spray chamber (SC) operating pressure of 4.0 psia and a steam supply pressure of 165 psia.

Evaluation of the test data acquired during these tests indicate that either the discrete axial or annular nozzle configuration integrated into a CBD, with an annular throat length of 1.5 L/D at the nominal injection position, would be suitable to carry forward from the SB's perspective. Selection between these two then becomes more a function of constructability and implementation than performance. L/D also has some flexibility, and final L/D selection can be a function of constructability issues within a limited range.

Introduction

NASA's Plum Brook Station's Spacecraft Propulsion Research Facility (B-2) is a unique facility combining space thermal-vacuum simulation with the ability to "hot-fire" a rocket engine. This combination yields a highly desirable capability to qualify and certify upper stage engine system ignition and restart under space conditions. Historically

utilized in the development of the LOX/LH₂ Centaur upper stage (using two RL-10, 67-kN (15 000-lbf) engines), the B-2 is now being considered for application to the next generation of space systems involving engine ignition and operations at higher thrust levels while in and beyond Earth orbit.

To accommodate the higher thrust engines, a preliminary design study was conducted on the exhaust diffuser. The preliminary design is novel in that it incorporates a steam blocker (SB) upstream of a conventional center-body diffuser (CBD). Very little data could be found to characterize the expected performance of this configuration, and consequently, a scale model test program was implemented to build up this data.

The B-2 test stand is unique in its flow scheme, because it incorporates a large direct contact spray cooler between the rocket engine diffuser and the steam jet ejection exhaust system. The cooler has the distinct advantage of being able to cool the rocket engine exhaust gases to a temperature slightly above ambient, prior to ejection. This feature is at the expense of dynamic lag in system response, which is a disadvantage during engine shutdown. The incorporation of the hysteresis-free SB into the supersonic rocket engine CBD eliminates this disadvantage and provides the capability to achieve a virtually "bump-free" shutdown (which will be referred to as "soft shutdown" for the remainder of this report).

The SB requires a pumping curve with no hysteresis and two actions outside of its envelope to achieve a dry soft shutdown.

(1) A means of throttling steam pressure (flow)

(2) A means of discharge filling the test chamber (still at altitude) with dry, inert gas as the test chamber pressure equalizes to the spray chamber (SC) pressure (only required to maintain a dry, exhaust-gas-free test article environment)

The CBD is chosen for these tasks because its inherent short overall length also offers a throat configuration that is uniquely suited to an annular or ring nozzle blocking system. Therefore, the interference with the engine nozzle is avoided.

This report provides the results of the cold-flow testing on the SB-only portion of the configuration. The substantially more difficult hot-fire testing, where both simulated engine and SB are flowing, has been deferred to a future date. Please see Appendix A for a list of acronyms used in this report.

Test Objectives

The test report addresses the cold-flow testing's three primary objectives:

(1) Demonstrate proof-of-concept for upstream integration of steam blocker (SB) with a center-body diffuser (CBD).

Quantify expected performance of SB at various discharge pressures

- Investigate start conditions at low discharge pressure (0.2 psia or lowest feasible pressure)
- Investigate sensitivity to unstart because of increasing discharge pressure
- Investigate a range of “nominal” SC operating pressures (3 to 7 psia)
- Identify the test chamber pressure that results during SB operation (over the full range of discharge pressures)

(2) Provide test data on the expected performance of preliminary design concepts that will support the development of a refined final design.

Identify sensitivities and effectiveness of

- Steam injection point upstream of center-body second throat
- SB nozzle geometry (step change with annular throat, step change with discrete throats, flush wall with scarfed nozzles, and nozzle contour)
- Length-to-diameter ratio (L/D) sensitivities (length is the center-body throat length and diameter is at the center-body throat).

(3) Gain an understanding of the variables that influence the expected soft shutdown performance of the integrated SB/diffuser. (Note: Transients involving engine shutoff performance are not part of this objective.)

Test Apparatus and Setup

The scale model design is based on the preliminary design by Carl Kastner Jr. (Ref. 1) for a full-scale diffuser system based on a SC operating pressure of 4.0 psia, with SB flow using a 165-psia supply pressure. See Appendix B for additional hardware details.

Testing was performed at John H. Glenn Research Center in the 1NW cell of the Engine Research Building. The test rig was attached to an existing bypass line that is connected to the Center's altitude exhaust system, which provides a continuous vacuum source of great capacity.

Hardware utilized for this test included program-specific elements and test support systems listed below.

Program-specific

(1) A 2.25-percent scale model, based on diameter, of the proposed diffuser (Dwg no. G020206MA000)

(2) Three separate nozzle blocks to simulate methods of steam injection for the SB

- Annular nozzle block
- Discrete axial nozzle block
- Scarfed nozzle block

- (3) Center-body inserts to create different L/D) ratios
- (4) Inlet plenum (simulates test chamber)
- (5) Center-body axial adjusting mechanism
- (6) Shell inserts for varying the nozzle block location with reference to the diffuser throat

Test support

(1) Pressure sensor (for data points PSTTC1, PSTTC2, and PSTDD1)—Pressure Systems Incorporated System 8400, model no. 15 psia PCU, range 0 to 10 psia, SN 1055

(2) Pressure sensor (for data points PMFPUP and PMFPDN)—Pressure Systems Incorporated System 8400, model no. 23 psia PCU, range 0 to 10 psia, SN 1343

(3) Pressure sensor (for data points PSTALTEX and PAMB)—Pressure Systems Incorporated System 8400, model no. 45 psia PCU, range 0 to 30 psia, SN 1245

(4) Pressure sensor (for data points PSTB1, PSTB2, PSTRM1, PSTRM2, PSTPLE1 and PSTPLE2)—Pressure Systems Incorporated System 8400, model no. 300 psia PCU, range 0 to 265 psia, SN 1019

(5) Temperature sensors (for data points TAMB, TASME1, TCA450, TSB1, TSB2, and TDD1)—Type E thermocouple, Hy-Cal Engineering Thermocouple Reference Bloc Model no. 401, SN 922885, range -328 °F to 1652 °F

(6) Mass flowmeter for blocker flow measurement (for data point MDOTSTM): Micromotion Coriolis Mass Flow Meter, model no. CMF050M315NRAUEZZZ, SN 11028122, range 0 to 4.17 pps

(7) ESCORT data system

(8) Air inlet manifold

(9) Mass flow rate nozzles (critical flow) to provide secondary flow (pps free dry air (FDA) at test stand ambient temperature and pressure) in combination as follows:

Case no.	pps FDA
1	0.0013
2	.0047
3	.0122
4	.0248
5	.0699

Appendix B contains setup illustrations and critical flow nozzle details.

The test setup is shown in Figure 1, scale model hardware pieces in Figure 2, and a view looking down into the assembled hardware in Figure 3.

Figures 4, 5, and 6 are the three different nozzle blocks. These represent the three different methods of injecting steam into the diffuser. Each has their advantages and disadvantages in terms of complexity of fabrication, maintenance, and installation. These tests are specific toward performance only, with the results adding to the pros and cons for a final selection.



Figure 1.—Test configuration.



Figure 2.—Scale model hardware pieces.



Figure 3.—Internal assembled view (scarfed nozzle block).



Figure 4.—Discrete axial nozzle block.



Figure 5.—Annular nozzle block.



Figure 6.—Scarfed nozzle block.

The annular nozzle block was reworked prior to testing because of the annular slot being visually nonsymmetric. Post rework, the nozzle slot was significantly more symmetric. Throat area measurements were taken of all three nozzle blocks and compared to the drawings (see Appendix C). Deviation of measured values among the nozzle blocks caused a need to introduce a correction factor to allow comparison of the data. More details on the correction factor are included in the Analysis and Discussion of Test Results portion of this report.

Test Plan and Procedure

The test plan (Ref. 2) identified the test matrix, objectives, and other details. This section describes the basic test procedure and changes to the test matrix as a result of testing.

During the development of the test plan, it was recognized that attempting to simulate engine flow simultaneously with a SB flow would be no easy task because of significant differences in the fluid properties. Subsequently, the overall testing was split into a hot-fire test, where the combined engine and SB flow would be explored, and a cold-flow test for the SB only. Hot-fire testing has been deferred.

For the cold-flow tests, there was discussion about which fluid to use in the SB. NASA Glenn has a readily available source of high-pressure air making it a logical choice as a blocker fluid. Steam at Glenn is not readily available as a test fluid. Aerodynamic similarity can be made between the air and steam fluids for this cold-flow case where needed (Ref. 3).

Testing included a simulated discharge fill of nitrogen into the test chamber. Implemented through the use of critical flow nozzles, the effects of varying the quantity of mass flow were explored using ambient air that surrounded the test setup. Identified throughout this report as “secondary flow,” the purpose was to gain an understanding of how this gaseous discharge fill would affect the performance of the diffuser. The general test procedure is described below.

The system performance test consisted of starting the drive pressure at the diffuser exit pressure and increasing the drive pressure until the start point had been reached and passed. Subsequently, the procedure was reversed (by reducing the drive pressure) until the diffuser exit pressure has been reached. The counterprocedure was also used, starting with the maximum available drive pressure and increasing and decreasing the diffuser exit pressure.

During the test operation the blocker performance curve was observed in real time by an electronic plot of system drive pressure ratio (P_c/P_a) against diffuser rise ratio (P_d/P_a). See Figure 7 for locations of P_a , P_c , and P_d .

After the performance curve was established under zero secondary flow (load) conditions, a similar test series was run with the known air inflow to the simulated altitude chamber. This test uncovered sequentially small American Society of Mechanical Engineers (ASME)-type critical flow nozzles that permitted atmospheric air to flow into the altitude chamber under known conditions.

The secondary flow rate is then expressed in terms of the ejector industry standard, which is FDA. The standard is presented in Reference 4.

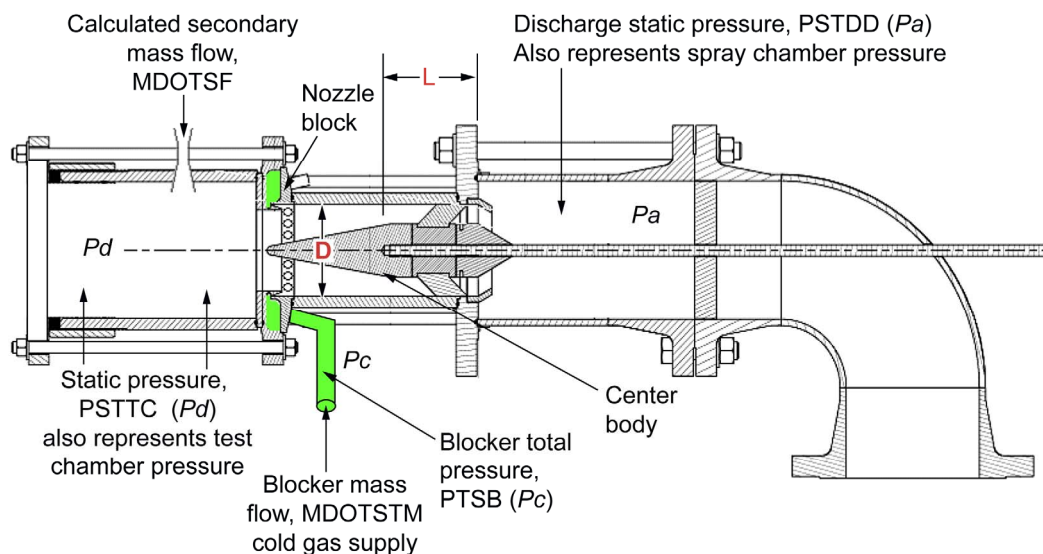


Figure 7.—Test data recording locations and notations (length (L), diameter (D)).

Blocker Model Test Sequence

Each distinct model hardware configuration was tested by operating the blocker and diffuser combination over a range of blocker inlet-to-diffuser exit pressure ratios.

The variables available to control this overall ratio were the inlet total pressure (P_c) to the model blocker nozzle plenum via an upstream proportional globe valve and the diffuser exit pressure (P_a) via a mass flow plug valve in the exhaust line. Each of these variables could be controlled independently. For ease of testing, most test sequences were completed varying only the blocker supply total pressure (PTSB), leaving the diffuser mass flow plug at the full open position.

A typical test sequence for a model hardware configuration was as follows:

- (1) Model initially at ambient pressure and zero flow.
- (2) Diffuser exit mass flow plug valve opened to evacuate the model to vacuum conditions ($P_d/P_a = 1$, $P_c/P_a = 1$).
- (3) Cold gas supply globe valve opened until a blocker plenum pressure (P_c) of ~ 10 psia achieved. Once at equilibrium, a data point was recorded.
- (4) Blocker plenum supply pressure (P_c) increased to ~ 20 psia and after equilibrium a data point was recorded.
- (5) Blocker supply pressure (P_c) increased to ~ 40 psia and a data point recorded.
- (6) Additional points were recorded with increasing blocker supply pressure until the diffuser performance plot (available in quasi-real time) indicated that the diffuser was started and operating in the choked region. Data points were recorded at smaller pressure increase intervals near the start point to record maximum blocker performance, which was determined by observation of the performance plot on the data system display.
- (7) From this maximum value, the blocker supply pressure (P_c) was lowered in 10- or 20-psi intervals and data points recorded to observe whether or not the pressure decreasing performance profile was the same as pressure increasing performance. Again, finer intervals were chosen based on performance near the start point (at the elbow in Figs. 8 and 9) as this is the performance point of the greatest interest.
- (8) At conclusion of the data gathering, the cold gas supply valve was closed and the model returned to vacuum conditions at zero flow ($P_d/P_a = 1$, $P_c/P_a = 1$).
- (9) Model vented to ambient conditions.
- (10) Test sequence completed.

Test Matrix Modifications

After some of the initial tests were conducted, the test matrix was reviewed based on test time and preliminary review of the test data. It became obvious that there were too many secondary flow test points that did not represent any significant change. Secondary flow case nos. 1 and 2 showed very little change, and secondary flow case nos. 3 and 4 showed very little change. Consequently, the number of secondary flow test

setups was reduced from five to three (deleted case nos. 1 and 3 from the remaining tests) for the final several test runs. One objective of this change was to decrease the amount of test time spent collecting data that will not affect the outcome.

Another test matrix modification was made to increase the test setup range. The original plan called for center-body L/D ratios of 1.5, 2.0, and 2.5. At an August 9, 2007, meeting with team members, a decision was made to gather a few test points using an L/D of 0.75 and eliminate the 2.0 L/D tests. The final “as-tested” test matrix is included in Table I.

Analysis and Discussion of Test Results

Test data is included in the appendixes to this report. The following paragraphs are organized based on the objectives of the test. Testing was accomplished using air as the blocker media instead of steam. For this section, any data related to the function of the SB will be referred to as “blocker.”

Objective 1.—Demonstrate proof-of-concept for upstream integration of steam blocker (SB) with a center-body diffuser (CBD)

This primary objective was decomposed into four individual lower-level objectives for the purpose of this test program. They are to quantify expected performance of SB at various discharge pressures for each of the following:

- (1a) investigate start conditions at low discharge pressure (0.2 psia or lowest feasible pressure)
- (1b) investigate sensitivity to unstart due to increasing discharge pressure
- (1c) investigate a range of “nominal” SC operating pressures ($P_a = 3$ to 7 psia)
- (1d) identify the test chamber pressure (P_d) that results during SB operation (over the full range of discharge pressure)

Objective 1a.—Investigate start conditions at low discharge pressure (0.2 psia or lowest feasible pressure)

The test setup with the tie-in to the central services line only allowed the lowest feasible discharge pressure to be 1.7 psia.

Figure 8 shows data based on this discharge pressure, providing a comparison of the data gathered for the annular, discrete axial, and scarfed nozzles. The annular and discrete axial nozzles use the same general geometry; however, the annular nozzle has a measured throat area larger than the discrete axial (0.00178 to 0.001235 ft²), with both being above the designed target value. To compensate for this throat area difference, a correction factor has been applied to the blocker pressure data for all three nozzle blocks. Multipliers of 1.58 for the annular nozzle, 1.13 for the discrete axial nozzle, and 1.13 for the scarfed nozzles were used in generating the related charts in this report. See Appendix C for the hardware’s throat area evaluation.

TABLE I.—B-2 DIFFUSER SCALE MODEL TEST PLAN¹

Config. no.	Blocker nozzle configuration	Centerbody length	Nozzle-center-body throat offset	Secondary flow	Config. no.	Blocker nozzle configuration	Center-body length	Nozzle-center-body throat offset	Secondary flow
1	Annular	1.5D ²	Nom. ³	None	40	Discrete 20	1.5D	Nom. 3.0-in.	Case 5
2	Annular	1.5D	Nom.	Case 2	41	Discrete 20	1.5D	Nom. 4.0-in.	None
3	Annular	1.5D	Nom.	Case 4	44	Discrete 20	1.5D	Nom. 4.0-in.	Case 5
4	Annular	1.5D	Nom.	Case 5	45	Discrete 20	0.75D	Nom.	None
5	Annular	1.5D	Nom. 1.0-in.	None	46	Discrete 20	0.75D	Nom. 3.0-in.	None
6	Annular	1.5D	Nom. 1.0-in.	Case 2	47	Discrete 20	2.5D	Nom.	None
7	Annular	1.5D	Nom. 1.0-in.	Case 4	48	Discrete 20	2.5D	Nom. 3.0-in.	None
8	Annular	1.5D	Nom. 1.0-in.	Case 5	49	Scarfed 20	1.5D ¹	Nom. ²	None
9	Annular	1.5D	Nom. 2.0-in.	None	50	Scarfed 20	1.5D	Nom.	Case 1
10	Annular	1.5D	Nom. 2.0-in.	Case 2	51	Scarfed 20	1.5D	Nom.	Case 2
11	Annular	1.5D	Nom. 2.0-in.	Case 4	52	Scarfed 20	1.5D	Nom.	Case 3
12	Annular	1.5D	Nom. 2.0-in.	Case 5	53	Scarfed 20	1.5D	Nom.	Case 4
13	Annular	1.5D	Nom. 3.0-in.	None	54	Scarfed 20	1.5D	Nom.	Case 5
14	Annular	1.5D	Nom. 3.0-in.	Case 2	55	Scarfed 20	1.5D	Nom. 1.0-in.	None
15	Annular	1.5D	Nom. 3.0-in.	Case 4	56	Scarfed 20	1.5D	Nom. 1.0-in.	Case 2
16	Annular	1.5D	Nom. 3.0-in.	Case 5	57	Scarfed 20	1.5D	Nom. 1.0-in.	Case 4
17	Annular	1.5D	Nom. 4.0-in.	None	58	Scarfed 20	1.5D	Nom. 1.0-in.	Case 5
18	Annular	1.5D	Nom. 4.0-in.	Case 2	59	Scarfed 20	1.5D	Nom. 2.0-in.	None
19	Annular	1.5D	Nom. 4.0-in.	Case 4	60	Scarfed 20	1.5D	Nom. 2.0-in.	Case 2
20	Annular	1.5D	Nom. 4.0-in.	Case 5	61	Scarfed 20	1.5D	Nom. 2.0-in.	Case 4
21	Annular	0.75D	Nom.	None	62	Scarfed 20	1.5D	Nom. 2.0-in.	Case 5
22	Annular	0.75D	Nom. 3.0-in.	None	63	Scarfed 20	1.5D	Nom. 3.0-in.	None
23	Annular	2.5D	Nom.	None	64	Scarfed 20	1.5D	Nom. 3.0-in.	Case 2
24	Annular	2.5D	Nom. 3.0-in.	None	65	Scarfed 20	1.5D	Nom. 3.0-in.	Case 4
25	Discrete 20	1.5D ¹	Nom. ²	None	66	Scarfed 20	1.5D	Nom. 3.0-in.	Case 5
26	Discrete 20	1.5D	Nom.	Case 2	67	Scarfed 20	1.5D	Nom. 3.78-in.	None
27	Discrete 20	1.5D	Nom.	Case 4	68	Scarfed 20	1.5D	Nom. 3.78-in.	Case 2
28	Discrete 20	1.5D	Nom.	Case 5	69	Scarfed 20	1.5D	Nom. 3.78-in.	Case 4
29	Discrete 20	1.5D	Nom. 1.0-in.	None	70	Scarfed 20	1.5D	Nom. 3.78-in.	Case 5
32	Discrete 20	1.5D	Nom. 1.0-in.	Case 5	71	Scarfed 20	0.75D	Nom.	None
33	Discrete 20	1.5D	Nom. 2.0-in.	None	72	Scarfed 20	0.75D	Nom. 3.0-in.	None
36	Discrete 20	1.5D	Nom. 2.0-in.	Case 5	73	Scarfed 20	2.5D	Nom.	None
37	Discrete 20	1.5D	Nom. 3.0-in.	None	74	Scarfed 20	2.5D	Nom. 3.0-in.	None

¹Blocker supply pressure 0 to 160 psia.²D is diffuser duct major diameter.³Nom. = Nominal position. Nominal offset between the nozzle exit plane and the center-body annular throat is approx. 4.75 in.

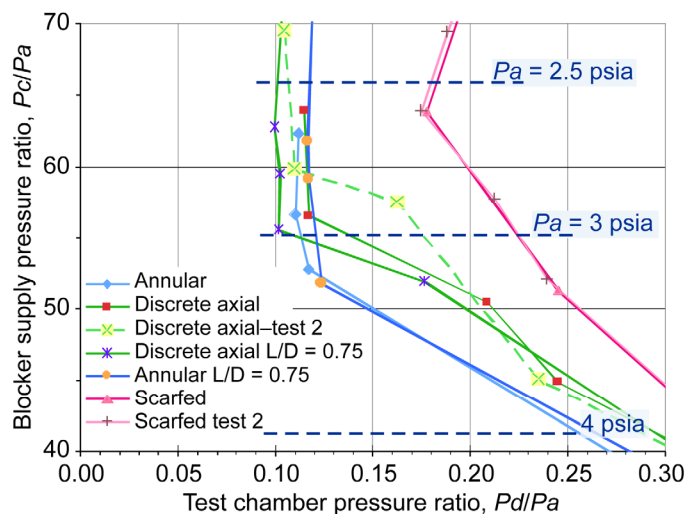


Figure 8.—Starting performance on rising blocker pressure (nominal position, no secondary flow).

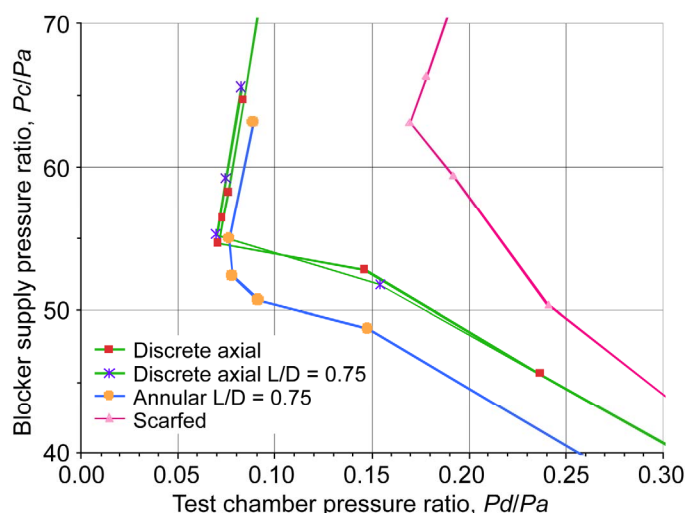


Figure 9.—Unstart performance comparison with increasing discharge pressure (nominal position, no secondary flow).

In Figure 8, the data is presented with lines connecting the data points. These lines are shown only to assist in following the data points for the various configurations and do not represent real values. Data is plotted for the nominal location only with blue lines for annular nozzle points, green lines for discrete axial nozzles, and reddish lines for the scarfed nozzles. This graph provides the data for the “no secondary flow” cases. With the “start” condition occurring at the knee in the graph, the data shows blocker supply pressure ratios in the range of 52 to 64 for low discharge pressures. On the graph,

three lines are shown to represent discharge pressures of 2.5, 3.0, and 4.0 psia for a blocker supply pressure of 165 psia. It is important to note that the information contained in this report must be corrected to account for simulating steam with ambient temperature air. Consequently, the numbers are only an approximation to what may be expected in an actual case. The scarfed nozzle block performance was significantly less than the annular and discrete axial nozzle blocks in this configuration.

Objective 1b.—Investigate sensitivity to unstart due to increasing discharge pressure

Figure 9 illustrates good consistency in the unstart point with the start point in both the scarfed nozzle and discrete axial nozzle blocks. Unfortunately, there was no data available for the annular nozzle block at the L/D = 1.5 configuration for increasing discharge pressure. Annular nozzle data at the L/D = 0.75 configuration is plotted, but does not exhibit a distinct unstart point.

Objective 1c.—Investigate a range of “nominal” spray chamber operating pressures (3 to 7 psia)

Tests supporting Objective 1c occurred as a subset of the testing for Objective 1d. Discussion is included with Objective 1d.

Objective 1d.—Identify the test chamber pressure that results during steam blocker (SB) operation (over the full range of discharge pressures)

The test was run by using air to simulate steam; consequently, the test chamber pressure will be somewhat different in the full up case. Looking only at the discrete axial nozzle data, there were two series of tests run with varying discharge pressure. They involved different injection locations and used different amounts of simulated steam for the blocker. In one case, a test chamber pressure reached a low of 0.23 psia and the other 0.20 psia. As expected, the greater blocker mass flow rate held off a higher discharge pressure. Increasing the discharge pressure above a critical value (the “start” point) causes the test chamber pressure to go up linearly with a slight positive slope.

For the greater blocker flow rate, the transition point occurred at about 3.0 psia while the lower blocker flow was at about 2.0 psia. The numbers are approximate as there is hysteresis when approaching the critical point through increasing pressure versus decreasing pressure. Keep in mind that these numbers were generated with no secondary flow.

While reaching the design point of 4.0 psia discharge pressure before impacting test chamber conditions is not depicted in Figure 10, the deviations are most likely a result of using air to simulate steam and the slightly lower absolute pressure in the blocker supply line when compared with the blocker supply pressure design.

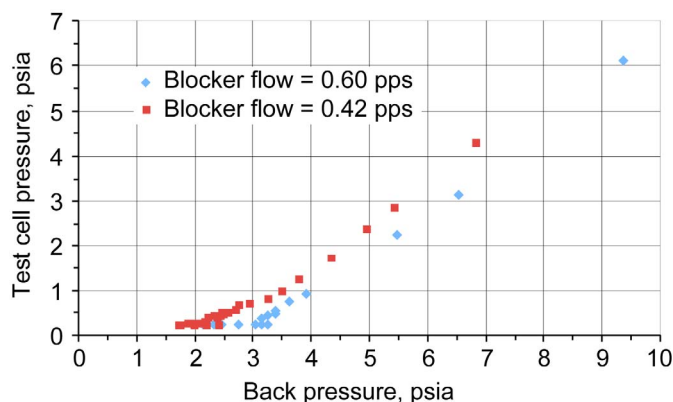


Figure 10.—Discrete axial nozzle test cell pressure versus back pressure (no secondary flow, length/diameter = 1.5 at different positions).

The primary objective of demonstrating proof-of-concept for integration of a SB upstream of a CBD has been successfully achieved. In all configurations tested, the CBD achieved a start condition in a consistent and well behaved manner, although some hysteresis was noted in configurations in which the nozzle block was close to the throat of the diffuser.

Objective 2.—Provide test data on the expected performance of the preliminary design concept to be fed into a refined final design

This primary objective was decomposed into three individual lower level objectives intended to examine some of the key physical parameters of the preliminary design concept.

2a.—Identify sensitivities and effectiveness of steam injection point upstream of center-body second throat.

2b.—Identify sensitivities and effectiveness of SB nozzle geometry (step change with annular throat, step change with discrete throats, flush wall with scarfed nozzles, and nozzle contour).

2c.—Identify sensitivities to the L/D ratio.

Objective 2a.—Identify sensitivities and effectiveness of steam injection point upstream of center-body second throat

Each of the nozzle blocks were varied in position to allow the injection point to move relative to the position of the center body. If the selected diffuser configuration is not so sensitive to blocker steam injection location, it will allow more freedom in the design process. Conversely, a very sensitive blocker steam injection location may limit layout options when integrating the diffuser into the test facility.

Test data for the various annular nozzle configurations are displayed in Figure 11. The graphs show that in the no-flow and small secondary flow cases there is little consequence to

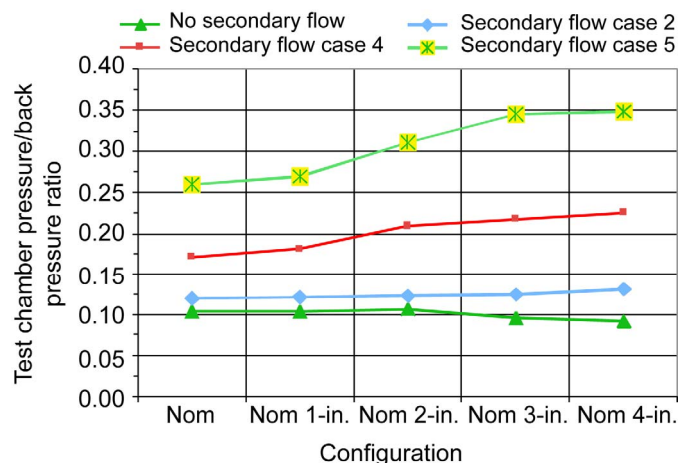


Figure 11.—Annular nozzle sensitivity to blocker media injection location (length/diameter = 1.5).

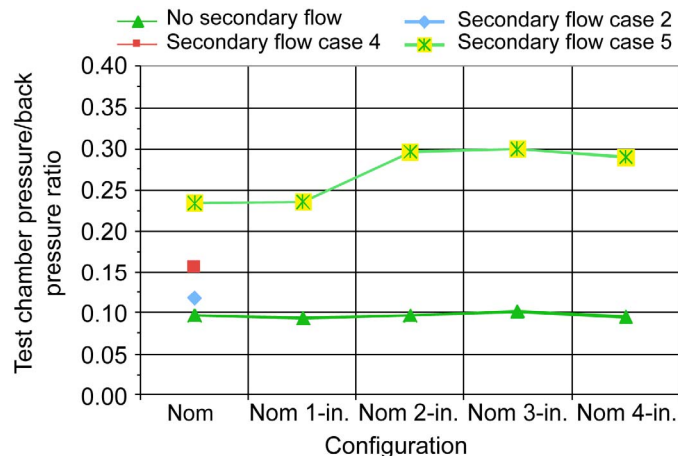


Figure 12.—Discrete axial nozzle sensitivity to blocker media injection location (length/diameter = 1.5).

location of the steam injection location for the annular nozzle. As the secondary flow load increases, there is a more pronounced performance difference. For secondary flow case no. 5, the secondary mass flow was about 19 percent of the injected blocker mass flow and represented the greatest pumping load in the test matrix. In the chart, a lower ratio is an indication of better performance (see explanation note 1). Using this metric, the optimal location would be nominal to nominal 1-in. with some room for error. The closer injection points to the center-body second throat do not perform as well.

With the discrete axial nozzles, the no secondary flow case yielded similar values to the annular nozzle across the board (see Fig. 12). This is expected as both nozzle blocks involve injecting the blocker media in a downward facing step at the same physical locations. As with the annular nozzle, injection location is not sensitive when considering the no

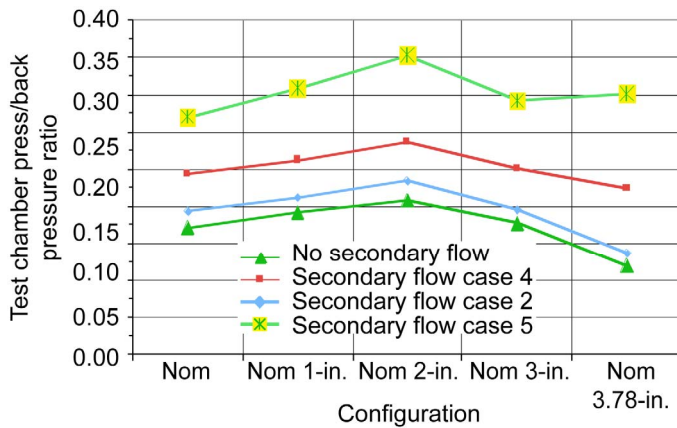


Figure 13.—Discrete scarfed nozzle sensitivity to blocker media injection location (length/diameter = 1.5).

secondary flow case. Secondary flow cases for this nozzle block show a similar pattern to the annular nozzle case when comparing the blocker media injection location. For this discrete axial nozzle block, the optimal location is also considered to be the Nominal to Nominal 1-in. area.

The scarfed nozzle block is geometrically different than the other two nozzle blocks. With no discharge ward facing step, the injection flow has a different angle to cover the same second throat diameter. In examining Figure 13, the scarfed nozzles do exhibit a sensitivity to location that appears in all $L/D = 1.5$ cases. The Nominal 2-in. location consistently performed worse no matter the secondary flow amount. It is clear that this location should be avoided if using the scarfed nozzle arrangement. For the no secondary flow case, the best location would be the Nominal 3.78-in. position. However, when considering secondary flow case no. 5, the nominal position appears to be the optimal location.

Optimal location from the tested configurations for steam injection for the three nozzle blocks are shown in Table II.

TABLE II.—OPTIMAL STEAM INJECTION LOCATIONS

Nozzle block	Best media injection location
Annular	Nominal to Nominal 1-in.
Discrete axial	Nominal to Nominal 1-in.
Scarfed	Nominal

In the data examined for this objective, secondary flow does play a factor when selecting an optimal design.

While the best blocker media injection location has been determined for the SB-only operation, these may not be the best locations when accounting for engine flow effects, which is especially true for the shrouded nozzle blocks (i.e., annular nozzle and discrete axial blocks) that provide a step change in diameter for the engine exhaust products. Locating these nozzle blocks closer to the throat of the center body distorts the primary rocket engine exhaust flow path and is not physically suited to the application. For this reason, the nominal position would be the preferred injection location.

Objective 2b.—Identify sensitivities and effectiveness of steam blocker (SB) nozzle geometry (step change with annular throat, step change with discrete throats, flush wall with scarfed nozzles, and nozzle contour)

The analysis in this section is being prepared utilizing the nominal position for all three blocks. Nominal 1-in. was not used since secondary flow case no. 5 data was not performed for the discrete axial configuration.

Using the test data from varying the blocker supply pressure, tables can be prepared to compare the nozzle blocks (Tables III and IV). For the no secondary flow case, the annular and discrete axial nozzle blocks test chamber pressure ratios are nearly identical (0.103 and 0.105, respectively).

TABLE III.—NO SECONDARY FLOW

Nozzle block	Config. no.	P_d/P_a test chamber pressure ratio	Blocker media mass flow rate
Annular	1	0.103	0.3404
Discrete axial	25	.105	.3442
Scarfed	49	.172	.3722

TABLE IV.—SECONDARY FLOW CASE NO. 5

Nozzle block	Config. no.	P_d/P_a test chamber pressure ratio	Blocker media mass flow rate
Annular	4	0.278	0.3449
Discrete axial	28	.236	.3064
Scarfed	54	.315	.3105

When considering secondary flow case no. 5, the discrete axial configuration shows a more pronounced difference (0.236 to the annular's 0.278). This may be a result of the flow in the annular nozzle being more concentrated around the OD where the discrete nozzle will direct a greater percentage of its flow toward the center and thereby performing better with secondary flow. It can be concluded from Tables III and IV and Figure 14, that for the actual test hardware as built, the discrete axial is the preferred configuration performing better over a greater range of secondary flow.

Since all the tested configurations in the 1.5 L/D ratio performed reasonably well, it can be said that none of the nozzle blocks or configurations were overly sensitive as to prevent operation.

A few tests were performed where the discharge pressure was varied while holding the blocker flow constant. Figure 15 plots another comparison using data from these tests to see how the discrete axial and scarfed nozzle blocks compared when operating at the same blocker mass flow rate. Both of these nozzles use the same area correction value making the comparison direct. From the Figure 15 graph (which is for no secondary flow), the two perform in similar fashion, and the discrete axial obtains a lower test chamber pressure.

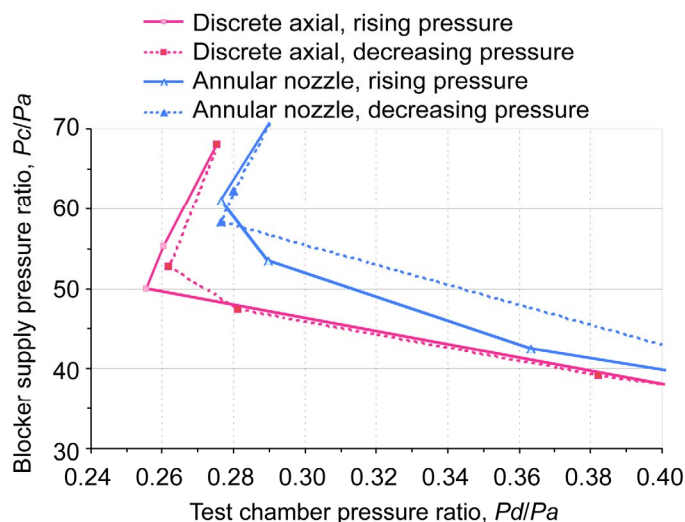


Figure 14.—Annular versus discrete axial performance (nominal position, secondary flow case 5).

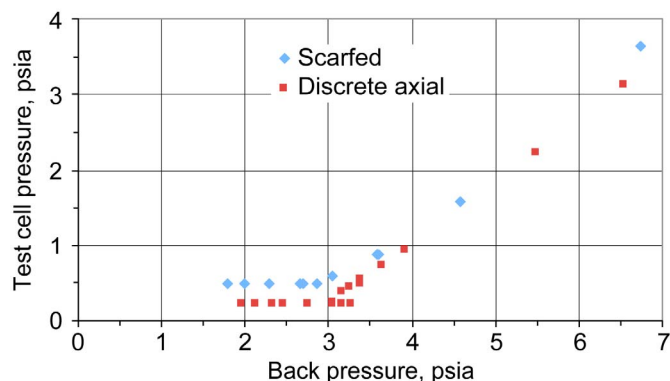


Figure 15.—Discrete axial versus scarfed performance, varying discharge pressure (blocker media = 0.61 pps, no secondary flow, nominal position).

There appears to be very little sensitivity in any of the three nozzle block configurations for the as-tested arrangements. Any of the three will perform when in their best blocker media injection position. When comparing the three for the best of the group, the discrete axial comes out as the preferred configuration for the 1.5 L/D ratio because of its superior performance in the secondary flow cases.

Objective 2c.—Identify sensitivities to the L/D ratio

Each of the three nozzle blocks were tested with different L/D ratios. Test data was not collected for secondary flow cases for either the 0.75 L/D or the 2.5 L/D configurations. Consequently, only the no secondary flow case can be compared. The data in Figure 16 is from the selected best performing points for each configuration. For these points, the

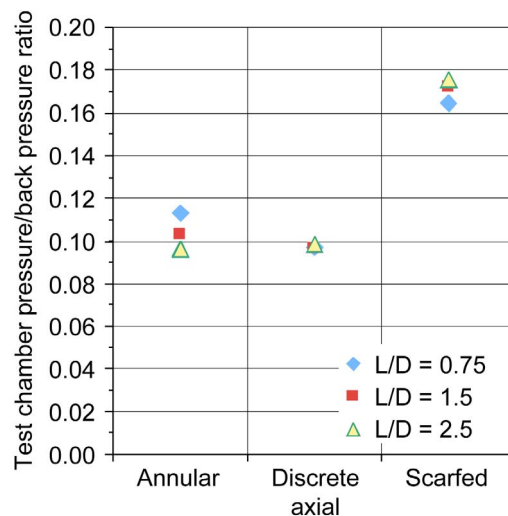


Figure 16.—Nozzle block length to diameter ratio (L/D) comparison (nominal position, no secondary flow).

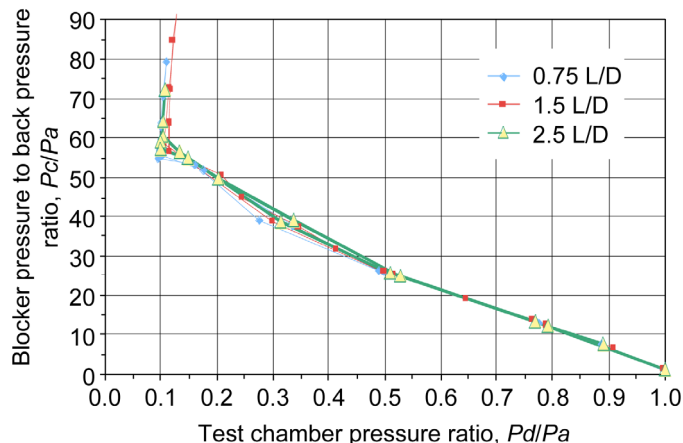


Figure 17.—Discrete axial nozzles, length to diameter ratio (L/D) performance comparison (nominal position, no secondary flow).

sensitivity of the blocker flow only operation to L/D ratios (within the range tested) does not appear to be significant. The scarfed configuration is the most sensitive as the combination of L/D change with blocker injection point position did have a moderate beneficial impact on its performance.

Checking the data for the nonoptimal points of blocker flow only, confirms that the L/D ratio is not a significant item within the range of L/D tested. Choosing the discrete axial nozzle block to demonstrate this, Figure 17 shows the consistency over the entire range.

When considering operation with blocker flow only, L/D ratios (within the range tested) are not a significant element in the performance of the CBD at the no secondary flow condition. This implies that other design constraints can be the driver for the final diffuser L/D design.

Objective 3.—Gain an understanding on the expected soft shutdown performance of the integrated steam blocker (SB)/diffuser

While the test program did not explicitly test shutdown methods, the test data can be reviewed to provide some qualitative evaluation for this objective.

Figure 18 provides insight into some of the soft shutdown for this system. What is not captured is the transient performance occurring during the shutdown of the test engine. This effect is expected to be investigated in a more advanced test, should the program be continued.

In Figure 18, the secondary flow effect is demonstrated by the progression of the performance curve from left to right. This effect simulates adding GN₂ into the test chamber, which will be part of the shutdown sequence to minimize moisture entry into the test chamber.

During this process, the steam supply pressure will be reduced to begin the process of equalizing the two chambers. In Figure 18, this reduction is represented by the curve tailing down to the right side of the graph. Simultaneously, the SC pressure is decreased by spray water system and the steam ejection system (although the same bump-free shutdown would occur without reduction in SC pressure, but at a higher absolute test chamber pressure). During the reduction of steam pressure, the GN₂ would be added to the test chamber, which also has the effect of trimming test chamber pressure by loading the SB. Steam supply would continue to be gradually decreased to shut off allowing the GN₂ to maintain a dry environment in the test chamber.

For the conditions where the diffuser is started and the SC pressure is high, the data collected during the varying discharge pressure tests provide evidence of how this system might perform. Figure 19 shows data collected during one of these varying discharge pressure tests and gives some indication of how the test chamber pressure might track the discharge pressure with the blocker flow rate remaining constant. In general, a pressure ratio will be maintained down to the design point after which the test chamber pressure will remain almost constant while the discharge pressure continues to decrease. Discharge pressure will reach a point where the ejector system hits its lowest suction pressure capability. After achieving that point, decreasing the blocker pressure becomes most feasible.

What is not captured is how the test chamber pressure increases at the moment of engine shutdown, where discharge pressure is high and test chamber pressure is very low. As previously mentioned, characterization of this transient should be evaluated if the program proceeds.

Some data was obtained; however, additional testing using a simulated engine flow is recommended. The dynamics of the transition to blocker flow only was not part of this testing. However, after the transient, the blocker flow provided consistent stable performance in minimizing shutdown effects.

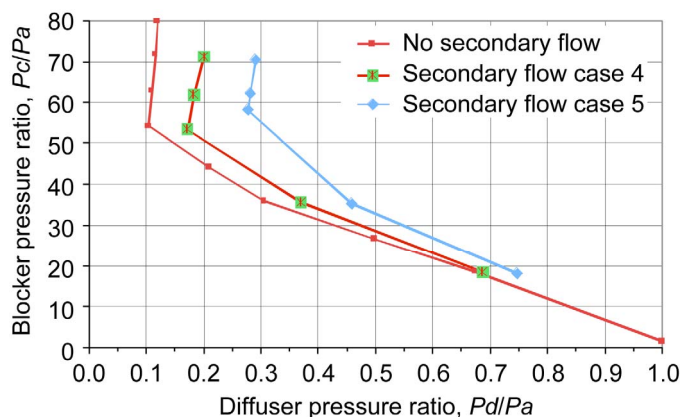


Figure 18.—Effect of secondary flow on performance curve (annular nozzle, length/diameter = 1.5, nominal position).

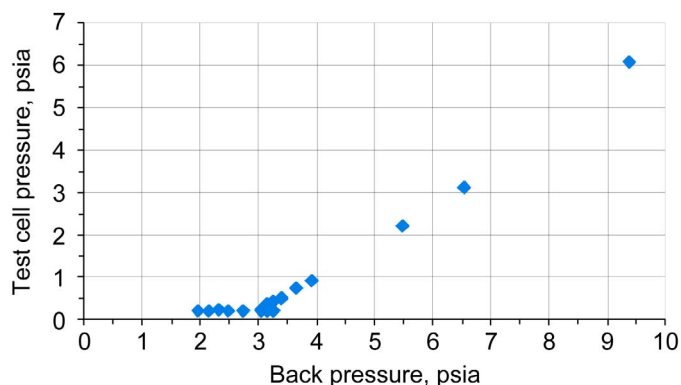


Figure 19.—Discrete axial back pressure effects (blocker flow = 0.060 pps, no secondary flow, nominal position, length/diameter = 1.5).

Notes

Anomalies

As the secondary flow increased to case no. 5 (maximum), flow effects were creating a difference in the two static-pressure taps in the test chamber. The lower static-pressure tap (located nearly directly opposite the largest flow orifice) was particularly subject to flow impact. For secondary flow case no. 5 analyses, only the lower pressure reading from the two pressure sensors is used for the comparisons.

Discharge pressure transducer (PSTDD) has a calibrated span up to 10 psia. During ambient no-flow conditions and when the discharge pressure was being varied, transducer readings above 10 psia do not have a calibration reference and therefore cannot be used for exacting calculations. This affects only a few points in the test data, and none that contribute to selection of the best configuration.

Steam Injection Method Pros and Cons

Some experiences gained during this testing program need to be recorded for future considerations.

Manufacturing tolerances with annular nozzles and alignment. The initial annular nozzle was found to be off-center. It was returned to the fabricator where the nozzle was re-welded. Afterward, the hardware was still off-center but to a much smaller degree. The test data represents this improved configuration, although some slight degradation of performance in this configuration probably remains.

Scarfed nozzle plume impingement (cooling concern). Depending upon actual final configurations, it is projected that the scarfed nozzle openings will be in the area of rocket exhaust plume impingement. There is concern that the impingement will result in increased erosion rates and a shorter life expectancy than the annular or discrete axial configurations.

General Notes

The pressure ratio of test chamber static pressure to discharge pressure static pressure (P_d/P_a) was used to allow comparisons between tests. Since the tests occurred over several different days and weeks, the discharge pressure was different for the tests. Discharge pressure is a function of the central exhaust systems performance at the time, which is in turn driven by the number of users and their various test conditions. With the diffuser being a pressure-ratio device, use of the pressure ratio is a valid comparison tool for the purpose of this evaluation.

The hardware design and configuration does have an effect that appears in some of the test data. For the annular and discrete axial nozzle blocks, the blocker media injection variation is created by physically moving the center body axially in the test setup. This structure causes the nose of the center body to protrude into the simulated test chamber and intercept the sonic flow from the secondary flow nozzles. As the center-body location gets moved inch by inch, it will ultimately protrude into the simulated test chamber by 4 in. This protrusion creates complicated flow patterns in the simulated test chamber as the flow deflects when it impinges on the center-body nose cone. Each change in center-body position creates a new flow pattern in the simulated test chamber, affecting the static pressure readings between the two pressure taps. Both the discrete axial and the annular nozzle blocks exhibited the same effect during the secondary flow case no. 5, as the nose cone progressively intercepts the secondary flow jets.

The scarfed nozzle configuration is not affected by center-body location because the method to move the center body is different. Here, a change in location is accomplished by adding a different spool piece, resulting in the center-body nose cone never entering into the simulated test chamber space, which produced a much more consistent reading in these pressure taps.

Conclusions

Design of the center-body diffuser (CBD) with an integral steam blocker (SB) requires knowledge of the maximum discharge pressure operating condition. For the 4.0-psia discharge pressure design point, the integrated SB/CBD concept has proven viable and has operated in accordance with the expected design basis.

Both the annular and the discrete axial nozzle configurations appear well suited for the job, and selection of which one to incorporate should be based on other factors such as fabrication, installation, maintenance, and cost rather than performance.

The performance curves have shown that the blocker is stable and has no instability or hysteresis in the configurations that are most likely to be utilized for the final design (i.e., the steam blocking configuration in which the nozzles are located as close as possible to the exit plane of the rocket engine).

The annular nozzle provided the best performance from the standpoint of starting pressure ratio and from the standpoint of diffuser rise ratio when no secondary flow is considered. The discrete axial nozzle configuration provided the best performance when secondary flow is taken into account.

The performance of the system in creating altitude was lower than anticipated (i.e., the test chamber pressure was not as close to zero as originally expected) and may warrant further development.

The performance of the system from the standpoint of starting pressure ratio was close to predictions, although the pressure ratio correction was higher than anticipated by approximately 16 percent (without correction for drive nozzle eccentricity).

Nozzle configuration, as it relates to expansion characteristics, is an area in which development would be advantageous, to improve the test chamber pressure (i.e., obtain higher altitude during blocker operation).

In general the addition of secondary flow will tend to stabilize the pumping of the ejector and will minimize or eliminate areas of instability. (This is a broad and generally true statement that is not necessarily fallout of the model study.)

Recommendations

The original plan called for a follow-on hot-fire test to explore simultaneous operation of the SB with flow from a simulated rocket nozzle. This advanced scale model program would establish transient performance characteristics and assist in development of shutdown techniques for the SB configuration. It is recommended that testing include development of more information for the system design and operating requirements, including steam pressure regulation techniques and transient effects caused by unexpected sudden engine shutdown. Also recommended is the ability of the updated scale model to include provisions for testing multiple

nozzle blocks so that performance improvements can be incorporated during the program.

In future tests, the method to inject secondary flow and the movement of the center body (axially) should be carefully considered so as to minimize the effects of the flow patterns in the simulated test chamber. Also part of this consideration is

the placement of the static pressure taps in the simulated test chamber to avoid flow impingement effects.

Glenn Research Center
National Aeronautics and Space Administration
Cleveland, Ohio
March 6, 2009

Appendix A.—Acronyms, Abbreviations, and Definitions

This appendix lists the acronyms and abbreviations used in this document as well as some of the important definitions.

Acronyms and Abbreviations

°F	degrees Fahrenheit
FDA	free dry air
GN2	gaseous nitrogen
L/D	length to diameter ratio
pps	pounds per second
psia	pounds per square in., absolute
D (or Dd)	diffuser duct major diameter
SC	spray chamber

Definitions

FDA	free dry air, as an abbreviation for “70 °F air equivalent,” a standard basis given in Reference 4 to define jet ejector loading.
P_a	Diffuser discharge static pressure

P_c	Total pressure of the blocker supply
P_c/P_a	Overall (or system) pressure ratio
P_d	Test chamber static pressure
P_d/P_a	Diffuser “rise” pressure ratio
P_d/P_c	Nozzle (or diffuser inlet) pressure ratio
Soft Shutdown	The ability to shutdown a test engine operating at altitude conditions without the consequence of a potentially damaging pressure wave ramming discharge into the engine from the higher pressure discharge conditions.
Start	The point at which an increase in overall drive pressure ratio no longer produces a strong reduction in diffuser rise ratio, but begins to show a gradual increase in diffuser rise ratio.
Unstart	The point at which a decrease in overall drive pressure ratio no longer produces a gradual reduction in diffuser rise ratio, but begins to show a strong increase in diffuser rise ratio (i.e., the opposite condition to “start”).

Appendix B.—Additional Scale Model Test Information

The hardware is configured in such a way as to permit the evaluation of three different nozzle concepts, the evaluation of nozzle position in the duct (beginning at the engine exit plane and ending at the diffuser throat entrance) and also to the evaluation of the impact of diffuser throat length (L/D).

Testing utilized the facility exhaust system to maintain the proper downstream pressure and dry air was used as the drive media (to simulate steam) in the blocker nozzle(s). Figure 20 provides an overall view of the test setup including a cross-sectional view. Figure 21 is a cross section of the scale model test hardware, illustrating the location of secondary flow injection points, blocker flow connections, exhaust connection, and the two hardware variables that are adjusted by exchanging hardware pieces.

Model basis: Aug 28, 2006 Preliminary Design Report (Ref. 1).

Secondary Mass Flow Information

Secondary mass flow nozzle throat diameters (in.) and flow (pps FDA at nominal test stand ambient temperature and pressure) are shown in Table V.

TABLE V.—SECONDARY MASS FLOW
NOZZLE THROAT DIAMETERS

Nozzle	Diameter, in. (pps FDA)
1	0.070 (0.0013)
2	0.115 (0.0034)
3	0.170 (0.0075)
4	0.250 (0.0126)
5	0.400 (0.0451)

Secondary mass flow cases utilized the nozzles by sequentially opening the nozzles

Case no. 1—Nozzle 1 open
(0.0013 pps FDA)

Case no. 2—Nozzles 1 and 2 open
(0.0047 pps FDA)

Case no. 3—Nozzles 1, 2, and 3 open
(0.0122 pps FDA)

Case no. 4—Nozzles 1, 2, 3, and 4 open
(0.0248 pps FDA)

Case no. 5—Nozzles 1, 2, 3, 4, and 5 open
(0.0699 pps FDA)

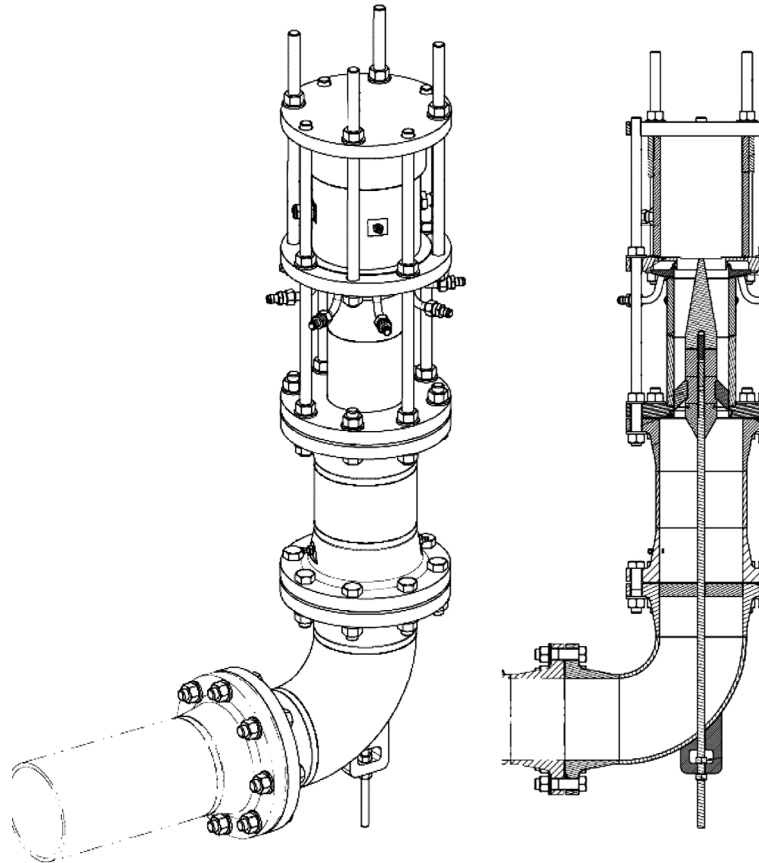


Figure 20.—Annular nozzle test configuration with cross section view.

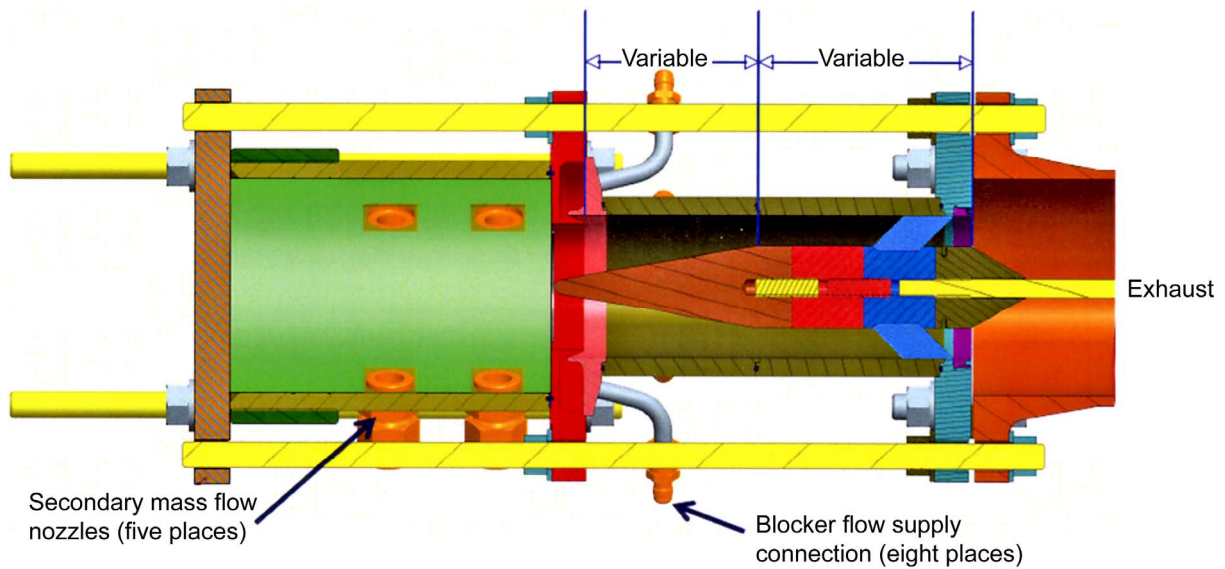


Figure 21.—Fluid flow connections.

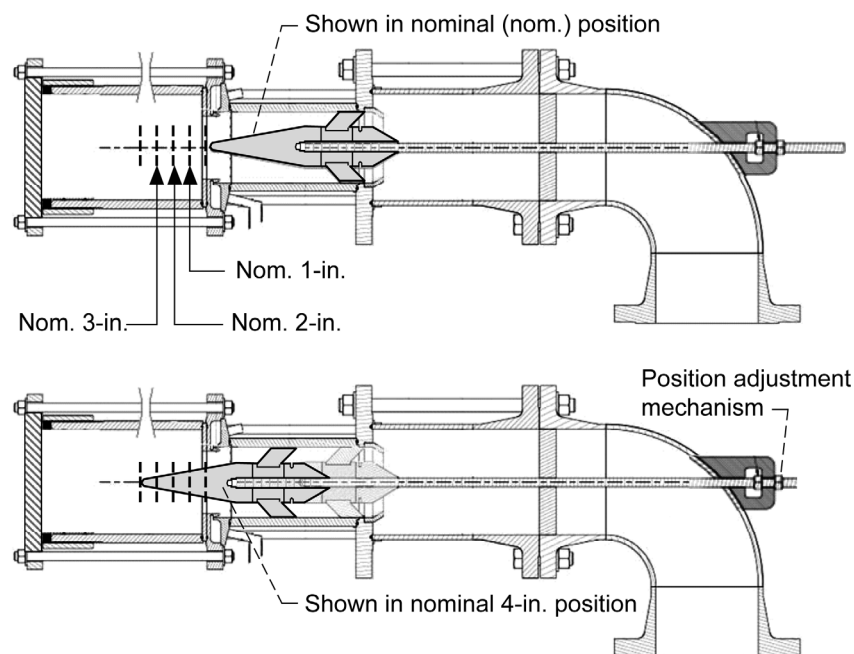


Figure 22.—Throat offsets for the annular and discrete axial nozzle blocks.

Nozzle Center-Body Throat Offset

Figures 22 and 23 illustrate the methods used to change the blocker media injection location. The annular and discrete axial nozzle blocks both use the same method of adjusting the physical location of the center body. That is, the scarfed nozzle block uses a method that provides different

length inserts upstream and downstream of the nozzle block. As the upstream insert gets longer, a shorter downstream insert is provided to maintain the same overall length between the test chamber and the discharge location. These two different methods were needed since the scarfed nozzle block does not utilize a step change in diameter at the point of blocker media injection.

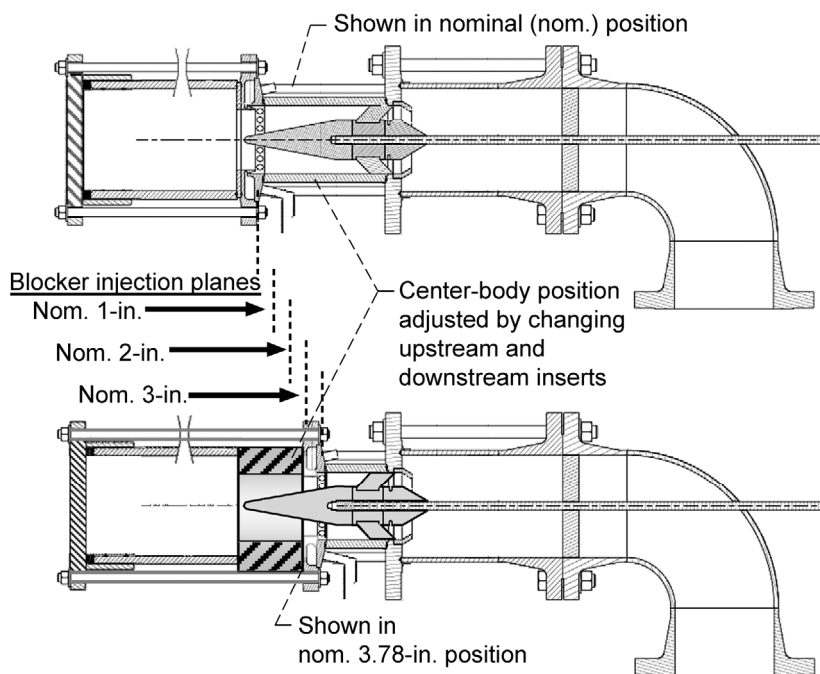


Figure 23.—Throat offsets for the scarfed nozzle blocks.

Appendix C.—Measured Nozzle Block Throat Areas

For this section, the nominal area or “nominal throat area” represents the throat area that would be obtained if the drawing

dimensions were met exactly. Figure 24 shows the dimensions and area of the annular, discrete, and scarfed nozzles.

Annular Nozzle Throat Dimensions and Area	
Throat Measurements	Throat OD
0.02 in.	4.000 in.
0.018 in.	
0.022 in.	
0.023 in.	
0.02 in.	
0.018 in.	
0.019 in.	
0.022 in.	
0.023 in.	
0.02056 in.	Average
Throat Area Based on Average Throat	Nominal Throat Area
0.00178 ft ²	0.00113 ft ²
Actual Area is 157.82 % of nominal area	
Pressure Ratio Multiplier	
1.58	
(a)	
Discrete Axial Nozzle Throat Dimensions and Area	
Throat Measurements	
0.106 in.	
0.106 in.	
0.106 in.	
0.106 in.	
0.106 in.	
0.107 in.	
0.107 in.	
0.106 in.	
0.106 in.	
0.107 in.	
0.106 in.	
0.107 in.	
0.107 in.	
0.107 in.	
0.107 in.	
0.106 in.	
0.107 in.	
0.106 in.	
0.106 in.	
0.106 in.	
Throat Area Based on Actual Throats	Nominal Throat Area
0.001234951 ft ²	0.00109 ft ²
Actual Area is 113.21 % of nominal area	
Pressure Ratio Multiplier	
1.13	
(b)	
Scarfed Nozzle Throat Dimensions and Area	
Throat Measurements	
0.105 in.	
0.105 in.	
0.106 in.	
0.106 in.	
0.106 in.	
0.106 in.	
0.106 in.	
0.106 in.	
0.107 in.	
0.107 in.	
0.108 in.	
0.108 in.	
0.109 in.	
0.108 in.	
0.108 in.	
0.107 in.	
0.106 in.	
0.107 in.	
0.106 in.	
0.105 in.	
Throat Area Based on Actual Throats	Nominal Throat Area
0.001239707 ft ²	0.00109 ft ²
Actual Area is 113.65 % of nominal area	
Pressure Ratio Multiplier	
1.13	
(c)	

Figure 24.—Nozzle throat dimensions and area. (a) annular (b) discrete (c) scarfed.

Appendix D.—Partial Test Data

Tables VI to XI present selected test data for a sampling of configurations. Descriptions of the column headings are presented below.

The following graphs (Figs. 25 to 32) provide typical results for the various nozzle blocks.

Config. no.—Configuration number from the test matrix.

Nozzle position—This is the location of the simulated steam (in our case air) injection point. The nominal location is most upstream location coincident with the nose cone tip. The Nominal 1-in. location is with the injection point being 1 in. closer to the center-body throat, Nominal 2-in. is 2 in. closer to the throat, and so forth.

Center-body length—This value is the body L/D ratio. Changes here represent a physical change to the center body (typically insertion of a plug).

Secondary flow—This column identifies which secondary flow case is being run. None represents the condition where the simulated test chamber has no intentional flow other than the blocker flow. Case no. 5 represents testing with the largest amount of secondary flow.

ESCORT RDG no.—ESCORT is the data acquisition system and the value here is the data systems reading number for the test point.

TAMB—Ambient temperature in the test facility, Rankine.

TSB1—Blocker flow temperature no. 1, Rankine. Provides the incoming air temperature to the blocker.

TDD1—Diffuser discharge temperature no. 1, Rankine.

MDOTSTM—Mass flow rate of the simulated steam blocker (here air) media, pounds per second.

MFPPPOS—Mass flow plug position, inches. Part of the test facility's hardware used to control discharge pressure.

PSTTC1—Test chamber static pressure no. 1, pounds per square inch, absolute (psia).

PSTTC2—Test chamber static pressure no. 2, psia.

PSTDD1—Diffuser discharge static pressure no. 1, psia.

PSTDD2—Diffuser discharge static pressure no. 2, psia (not used).

PMFPUP—Static pressure upstream of the mass flow plug, psia.

PMFPDN—Static pressure downstream of the mass flow plug, psia.

PSTALTEX—Static pressure of the facility altitude exhaust system, psia.

PAMB—Ambient test cell pressure, psia.

PTSBI—Total pressure no. 1 of the blocker supply, psia.

PTSB2—Total pressure no. 2 of the blocker supply, psia.

PTSBNORM—Normalized blocker pressure ratio with discharge pressure, nondimensional.

PSTCNORM—Normalized test chamber pressure ratio with discharge pressure, nondimensional

Nozzle area correction—Correction factor (multiplier) based on actual nozzle area compared to initial planned nozzle area, nondimensional (calculated value).

Corrected PSTBNORM—Normalized blocker pressure ratio corrected by multiplying PSTBNORM by the nozzle area correction, nondimensional (calculated value).

MDOTSF—Secondary flow mass flow rate, pounds per second. Values determined by calculation based on diameter of critical nozzle throat (i.e., not a measured value).

TABLE VI.—ANNULAR NOZZLE CONFIGURATION 1

Config. no.	Nozzle position	Center-body length	Secondary flow	ESCORT RDG	TAMB	TSB1	TDD1	MDOTSTM	MFPPPOS	PSTTC1	PSTTC2	PSTDD1	PSTDD2
1	Nominal	1.5D	None	536	531.19	531.26	535.64	0.0552	10.98	1.55	1.55	1.77	
1	Nominal	1.5D	None	537	531.12	529.60	535.19	.1084	10.98	1.25	1.24	1.78	
1	Nominal	1.5D	None	538	531.50	527.22	532.00	.2220	10.98	0.59	0.59	1.81	
1	Nominal	1.5D	None	539	531.65	525.89	524.23	.3374	10.98	.21	0.22	1.82	
1	Nominal	1.5D	None	540	531.38	526.51	521.32	.3616	10.98	.20	0.20	1.82	
1	Nominal	1.5D	None	541	531.32	526.74	516.28	.3930	10.98	.20	0.20	1.79	
1	Nominal	1.5D	None	542	531.29	527.99	511.25	.4492	10.98	.20	0.21	1.76	
1	Nominal	1.5D	None	543	531.37	529.12	510.82	.5035	10.98	.21	0.21	1.78	
1	Nominal	1.5D	None	544	531.42	531.77	513.81	.4411	10.98	.20	0.20	1.74	
1	Nominal	1.5D	None	545	531.46	531.78	518.60	.3866	10.98	.19	0.19	1.75	
1	Nominal	1.5D	None	546	531.47	531.63	524.42	.3404	10.98	.18	0.19	1.79	
1	Nominal	1.5D	None	547	531.56	531.59	525.58	.2771	10.98	.38	0.37	1.79	
1	Nominal	1.5D	None	548	531.54	531.44	529.26	.2243	10.98	.55	0.54	1.78	
1	Nominal	1.5D	None	549	531.55	531.30	528.91	.1637	10.98	.88	0.88	1.77	
1	Nominal	1.5D	None	550	531.54	531.41	527.16	.1138	10.98	1.19	1.19	1.76	
1	Nominal	1.5D	None	551	531.56	529.94	523.20	.0187	10.98	1.75	1.75	1.75	

ESCORT RDG	PMFPUP	PMFPDN	PSTALTEX	PAMB	PTSB1	PTSB2	PTSBNORM	Nozzle area correction	Corrected PTSBNORM	PTSCNORM	MDOTSF
536	1.78	1.76	1.77	14.34	10.35	10.31	5.85	1.58	9.24	0.878	0.000
537	1.79	1.78	1.78	14.34	20.02	19.98	11.24	1.58	17.77	.701	0.000
538	1.82	1.80	1.80	14.34	40.23	40.16	22.24	1.58	35.15	.329	0.000
539	1.84	1.79	1.79	14.34	60.79	60.70	33.38	1.58	52.74	.117	0.000
540	1.84	1.79	1.80	14.34	65.04	65.04	35.81	1.58	56.57	.110	0.000
541	1.85	1.80	1.80	14.34	70.59	70.59	39.46	1.58	62.35	.112	0.000
542	1.87	1.80	1.80	14.34	80.57	80.57	45.66	1.58	72.15	.116	0.000
543	1.88	1.80	1.80	14.34	90.11	90.11	50.49	1.58	79.78	.119	0.000
544	1.84	1.77	1.78	14.34	79.16	79.03	45.51	1.58	71.90	.116	0.000
545	1.82	1.76	1.77	14.34	69.64	69.56	39.79	1.58	62.87	.110	0.000
546	1.81	1.76	1.77	14.34	61.33	61.24	34.30	1.58	54.19	.103	0.000
547	1.80	1.77	1.77	14.34	50.29	50.20	28.06	1.58	44.34	.210	0.000
548	1.79	1.77	1.77	14.34	40.63	40.55	22.82	1.58	36.06	.306	0.000
549	1.78	1.76	1.77	14.34	29.84	29.77	16.85	1.58	26.63	.498	0.000
550	1.77	1.76	1.76	14.34	20.82	20.76	11.81	1.58	18.66	.676	0.000
551	1.76	1.75	1.76	14.34	1.78	1.76	1.01	1.58	1.60	1.000	0.000

TABLE VII.—ANNULAR NOZZLE CONFIGURATION 4

Config. no.	Nozzle position	Center-body length	Secondary flow	ESCORT RDG	TAMB	TSB1	TDD1	MDOTSTM	MFPPPOS	PSTTC1	PSTTC2	PSTDD1	PSTDD2
4	Nominal	1.5D	Case 5	581	531.40	532.08	528.29	0.0539	10.98	1.64	1.56	1.78	
4	Nominal	1.5D	Case 5	582	531.35	531.39	529.83	.1106	10.98	1.38	1.33	1.80	
4	Nominal	1.5D	Case 5	583	531.16	530.58	529.95	.1662	10.98	1.12	1.07	1.81	
4	Nominal	1.5D	Case 5	584	531.10	530.04	528.32	.2204	10.98	0.89	0.84	1.83	
4	Nominal	1.5D	Case 5	585	531.05	530.17	526.70	.2735	10.98	.69	.65	1.83	
4	Nominal	1.5D	Case 5	586	531.10	530.64	524.17	.3449	10.98	.56	.51	1.84	
4	Nominal	1.5D	Case 5	587	531.13	531.31	520.29	.3894	10.99	.53	.47	1.81	
4	Nominal	1.5D	Case 5	588	531.11	532.12	514.01	.4455	10.98	.55	.49	1.79	
4	Nominal	1.5D	Case 5	589	531.14	532.57	519.80	.3929	10.98	.53	.47	1.79	
4	Nominal	1.5D	Case 5	590	531.11	533.34	522.49	0.3700	10.99	.53	.47	1.81	
4	Nominal	1.5D	Case 5	591	531.15	533.52	527.10	.2223	10.98	.85	.80	1.79	
4	Nominal	1.5D	Case 5	592	531.22	533.51	526.03	.1122	10.98	1.35	1.30	1.77	

ESCORT RDG	PMFPUP	PMFPDN	PSTALTEX	PAMB	PTSB1	PTSB2	PTSBNORM	Nozzle area correction	Corrected PTSBNORM	PSTCNORM	MDOTSF
581	1.79	1.78	1.78	14.35	10.05	10.01	5.63	1.58	8.89	0.898	0.0699
582	1.81	1.79	1.79	14.35	20.30	20.26	11.29	1.58	17.83	.753	.0699
583	1.83	1.80	1.80	14.35	30.26	30.21	16.67	1.58	26.35	.603	.0699
584	1.84	1.81	1.81	14.35	39.99	39.91	21.84	1.58	34.51	.474	.0699
585	1.86	1.81	1.81	14.35	49.41	49.31	26.91	1.58	42.51	.363	.0699
586	1.87	1.81	1.81	14.35	62.10	62.00	33.80	1.58	53.40	.290	.0699
587	1.88	1.82	1.82	14.35	70.10	70.02	38.64	1.58	61.06	.276	.0699
588	1.90	1.81	1.81	14.35	80.12	79.98	44.67	1.58	70.58	.290	.0699
589	1.87	1.80	1.80	14.35	70.70	70.60	39.37	1.58	62.20	.280	.0699
590	1.86	1.80	1.80	14.35	66.73	66.61	36.90	1.58	58.30	.276	.0699
591	1.81	1.77	1.77	14.35	40.38	40.30	22.54	1.58	35.61	.459	.0699
592	1.79	1.77	1.77	14.35	20.60	20.55	11.60	1.58	18.33	.745	.0699

TABLE VIII.—DISCRETE AXIAL NOZZLE CONFIGURATION 25

Config. no.	Nozzle position	Center-body length	Secondary flow	ESCORT RDG	TAMB	TSB1	TDD1	MDOTSTM	MFPPPOS	PSTTC1	PSTTC2	PSTDD2
25	Nominal	1.5D	None	919	531.13	532.21	533.63	0.0386	10.98	1.60	1.60	1.76
25	Nominal	1.5D	None	920	531.12	531.84	533.92	.0735	10.98	1.39	1.39	1.76
25	Nominal	1.5D	None	921	531.17	531.15	534.13	.1127	10.98	1.14	1.14	1.76
25	Nominal	1.5D	None	922	531.19	530.11	533.78	.1509	10.98	0.91	0.91	1.76
25	Nominal	1.5D	None	923	531.13	528.92	530.37	.1907	10.98	0.73	0.73	1.77
25	Nominal	1.5D	None	924	531.13	528.72	528.02	.2271	10.98	0.62	0.62	1.78
25	Nominal	1.5D	None	925	531.17	528.83	526.97	.2721	10.98	0.44	0.44	1.78
25	Nominal	1.5D	None	926	531.13	529.97	525.90	.3073	10.98	0.37	0.37	1.79
25	Nominal	1.5D	None	927	531.20	531.61	524.83	.3442	10.98	0.21	0.21	1.79
25	Nominal	1.5D	None	928	531.23	533.11	520.76	.3832	10.98	0.20	0.20	1.77
25	Nominal	1.5D	None	929	531.28	534.56	517.26	.4277	10.98	0.20	0.20	1.74
25	Nominal	1.5D	None	930	531.26	536.28	513.18	.5019	10.98	0.21	0.21	1.74
25	Nominal	1.5D	None	931	531.18	539.88	510.30	.6124	10.98	0.24	0.23	1.68
25	Nominal	1.5D	None	932	530.95	540.31	521.60	.4215	10.98	0.20	0.20	1.71
25	Nominal	1.5D	None	933	530.93	540.22	530.30	.3442	10.98	0.18	0.18	1.74
25	Nominal	1.5D	None	934	530.89	539.96	531.39	.2313	10.98	0.53	0.52	1.75
25	Nominal	1.5D	None	935	530.91	539.42	532.34	.1538	10.98	0.87	0.87	1.74
25	Nominal	1.5D	None	936	530.90	539.14	529.25	.0797	10.98	1.33	1.33	1.74
25	Nominal	1.5D	None	937	530.93	536.85	527.01	.0425	10.98	1.73	1.73	1.73

ESCORT RDG	PMFPUP	PMFPDN	PSTALTEX	PAMB	PTSB1	PTSB2	PTSBNORM	Nozzle area correction	Corrected PTSBNORM	PSTCNORM	MDOTSF
919	1.77	1.76	1.76	14.34	10.24	10.21	5.81	1.13	6.57	0.909	0.000
920	1.77	1.76	1.76	14.34	19.42	19.39	11.02	1.13	12.45	.788	.000
921	1.77	1.75	1.76	14.34	29.61	29.58	16.82	1.13	19.01	.646	.000
922	1.77	1.75	1.76	14.34	39.47	39.44	22.38	1.13	25.29	.515	.000
923	1.78	1.76	1.76	14.34	49.76	49.71	28.10	1.13	31.75	.413	.000
924	1.79	1.76	1.77	14.34	59.17	59.15	33.25	1.13	37.58	.347	.000
925	1.79	1.76	1.76	14.34	70.78	70.75	39.70	1.13	44.86	.245	.000
926	1.80	1.77	1.77	14.34	79.87	79.83	44.67	1.13	50.47	.209	.000
927	1.80	1.76	1.76	14.34	89.48	89.44	50.03	1.13	56.53	.117	.000
928	1.82	1.77	1.77	14.34	99.88	99.86	56.58	1.13	63.94	.115	.000
929	1.83	1.77	1.77	14.34	111.36	111.31	63.94	1.13	72.25	.117	.000
930	1.86	1.78	1.78	14.34	130.79	130.77	74.98	1.13	84.72	.123	.000
931	1.89	1.78	1.77	14.34	159.56	159.55	94.98	1.13	107.33	.140	.000
932	1.80	1.74	1.74	14.34	110.16	110.09	64.36	1.13	72.73	.115	.000
933	1.76	1.72	1.72	14.34	90.05	89.99	51.72	1.13	48.44	.105	.000
934	1.76	1.74	1.74	14.34	60.40	60.35	34.45	1.13	38.93	.300	.000
935	1.75	1.73	1.74	14.34	40.31	40.27	23.12	1.13	26.12	.498	.000
936	1.75	1.74	1.74	14.34	20.88	20.82	11.99	1.13	13.55	.765	.000
937	1.74	1.73	1.74	14.34	1.86	1.80	1.06	1.13	1.20	.999	.000

TABLE IX.—DISCRETE AXIAL NOZZLE CONFIGURATION 28

Config. no.	Nozzle position	Center-body length	Secondary flow	ESCORT RDG	TAMB	TSB1	TDD1	MDTOSTM	MFPPPOS	PSTTC1	PSTTC2	PSTDD2
28	Nominal	1.5D	Case 5	985	530.88	542.60	531.09	0.0381	10.99	1.68	1.57	1.78
28	Nominal	1.5D	Case 5	986	530.79	543.13	532.93	.0722	10.99	1.51	1.43	1.79
28	Nominal	1.5D	Case 5	987	530.80	543.22	534.92	.1510	10.99	1.12	1.06	1.81
28	Nominal	1.5D	Case 5	988	530.73	543.57	534.41	.2292	10.99	0.75	0.70	1.80
28	Nominal	1.5D	Case 5	989	530.66	544.36	535.05	.3064	10.99	0.50	0.43	1.82
28	Nominal	1.5D	Case 5	990	530.72	546.69	533.72	.3411	10.99	0.51	0.44	1.83
28	Nominal	1.5D	Case 5	991	530.72	549.94	527.62	.4170	10.99	0.53	0.47	1.82
28	Nominal	1.5D	Case 5	992	530.50	550.99	536.55	.3196	10.99	0.51	0.44	1.80
28	Nominal	1.5D	Case 5	993	529.82	550.94	535.85	.2849	10.99	0.53	0.47	1.79
28	Nominal	1.5D	Case 5	994	528.87	550.61	535.73	.2314	10.99	0.69	0.65	1.76
28	Nominal	1.5D	Case 5	995	529.86	549.29	537.27	.1522	10.99	1.06	1.01	1.76
28	Nominal	1.5D	Case 5	996	530.05	548.30	535.23	.0746	10.99	1.46	1.38	1.75
28	Nominal	1.5D	Case 5	997	530.12	545.53	532.19	.0480	10.99	1.77	1.63	1.74

ESCORT RDG	PMFPUP	PMFPDN	PSTALTEX	PAMB	PTSB1	PTSB2	PSTBNORM	Nozzle area correction	Corrected PSTBNORM	PSTCNORM	MDOTSF
985	1.78	1.78	1.78	14.34	10.17	10.17	5.72	1.13	6.46	0.913	0.0699
986	1.79	1.78	1.78	14.34	19.33	19.33	10.82	1.13	12.22	.820	.0699
987	1.82	1.80	1.80	14.34	39.70	39.69	21.93	1.13	24.78	.602	.0699
988	1.81	1.78	1.78	14.34	60.14	60.10	33.45	1.13	37.80	.405	.0699
989	1.83	1.78	1.78	14.34	80.33	80.33	44.11	1.13	49.85	.256	.0699
990	1.84	1.79	1.79	14.34	89.37	89.37	48.94	1.13	55.31	.260	.0699
991	1.86	1.78	1.78	14.34	109.53	109.45	60.13	1.13	67.95	.275	.0699
992	1.81	1.76	1.76	14.34	84.04	84.02	46.63	1.13	52.69	.262	.0699
993	1.80	1.76	1.76	14.34	74.87	74.86	41.90	1.13	47.34	.282	.0699
994	1.78	1.75	1.75	14.34	60.93	60.93	34.56	1.13	39.05	.382	.0699
995	1.77	1.74	1.75	14.34	40.17	40.16	22.82	1.13	25.79	.587	.0699
996	1.75	1.74	1.75	14.34	19.79	19.78	11.31	1.13	12.78	.812	.0699
997	1.75	1.74	1.74	14.34	2.10	2.08	1.20	1.13	1.36	.976	.0699

TABLE X.—SCARFED NOZZLE CONFIGURATION 49

Config. no.	Nozzle position	Center-body length	Secondary flow	ESCORT RDG	TAMB	TSB1	TDD1	MDOTSTM	MFPPPOS	PSTTC1	PSTTC2	PSTDD1	PSTDD2
49	Nominal	1.5D	None	2	532.45			0.0000	10.99	1.71	1.71	1.71	
49	Nominal	1.5D	None	3	529.94			.0000	10.99	1.43	1.42	1.72	
49	Nominal	1.5D	None	4	530.73			.1552	10.99	1.00	0.99	1.77	
49	Nominal	1.5D	None	5	531.08			.2351	10.99	0.60	0.60	1.76	
49	Nominal	1.5D	None	6	531.24			.3063	10.99	0.43	0.43	1.77	
49	Nominal	1.5D	None	7	531.26			.3818	10.99	0.32	0.32	1.78	
49	Nominal	1.5D	None	8	531.13			.4521	10.99	0.37	0.36	1.78	
49	Nominal	1.5D	None	9	531.14			.5409	10.99	0.44	0.43	1.76	
49	Nominal	1.5D	None	10	531.05			.6075	10.99	0.49	0.49	1.78	
49	Nominal	1.5D	None	11	531.23			.5284	10.99	0.43	0.43	1.81	
49	Nominal	1.5D	None	12	531.35			.4614	10.99	0.37	0.37	1.78	
49	Nominal	1.5D	None	13	531.32			.3848	10.99	0.32	0.32	1.76	
49	Nominal	1.5D	None	14	531.43			.3065	10.99	0.42	0.42	1.75	
49	Nominal	1.5D	None	15	531.66			.2310	10.99	0.60	0.59	1.73	
49	Nominal	1.5D	None	16	531.89			.1540	10.99	0.95	0.94	1.71	
49	Nominal	1.5D	None	17	532.04			.0761	10.99	1.41	1.40	1.73	
49	Nominal	1.5D	None	18	532.08			.3544	10.99	0.37	0.37	1.80	
49	Nominal	1.5D	None	19	532.14			.4150	10.99	0.34	0.34	1.81	
49	Nominal	1.5D	None	20	531.11			.0000	10.99	1.71	1.71	1.71	

ESCORT RDG	PMFPUP	PMFPDN	PSTALTEX	PAMB	PTSB1	PTSB2	PTSBNORM	Nozzle area correction	Corrected PTSBNORM	PSTCNORM	MDOTSF
2	1.71	1.71	1.72	14.32	1.70	1.69	0.99	1.13	1.12	1.001	0.0000
3	1.72	1.72	1.73	14.32	18.36	18.34	10.65	1.13	12.04	0.828	.0000
4	1.77	1.76	1.77	14.32	40.87	40.82	23.08	1.13	26.08	.561	.0000
5	1.76	1.74	1.74	14.32	61.90	61.83	35.14	1.13	39.71	.340	.0000
6	1.78	1.75	1.75	14.32	80.51	80.44	45.44	1.13	51.35	.245	.0000
7	1.81	1.76	1.76	14.32	100.81	100.71	56.52	1.13	63.86	.178	.0000
8	1.82	1.76	1.76	14.32	118.96	118.83	66.63	1.13	75.29	.204	.0000
9	1.85	1.76	1.76	14.32	142.22	142.08	80.60	1.13	91.07	.246	.0000
10	1.87	1.77	1.76	14.32	160.53	160.37	90.15	1.13	101.87	.274	.0000
11	1.87	1.79	1.78	14.32	139.28	139.14	76.79	1.13	86.77	.235	.0000
12	1.82	1.76	1.75	14.32	122.41	122.30	68.77	1.13	77.71	.211	.0000
13	1.79	1.74	1.74	14.32	100.77	100.69	57.26	1.13	64.70	.182	.0000
14	1.75	1.73	1.73	14.32	80.42	80.33	45.98	1.13	51.96	.240	.0000
15	1.73	1.71	1.72	14.32	60.22	60.16	34.73	1.13	39.24	.344	.0000
16	1.71	1.70	1.71	14.32	40.32	40.28	23.54	1.13	26.60	.552	.0000
17	1.73	1.72	1.73	14.32	19.60	19.60	11.36	1.13	12.83	.813	.0000
18	1.81	1.78	1.78	14.32	93.80	93.71	52.13	1.13	58.90	.207	.0000
19	1.84	1.79	1.79	14.32	109.55	109.46	60.56	1.13	68.42	.188	.0000
20	1.71	1.71	1.72	14.32	1.76	1.79	1.04	1.13	1.17	1.000	.0000

TABLE XI.—SCARFED NOZZLE CONFIGURATION 54

Config. no.	Nozzle position	Center-body length	Secondary flow	ESCORT RDG	TAMB	TSB1	TDD1	MDOTSTM	MFPPPOS	PSTTC1	PSTTC2	PSTDD1	PSTDD2
54	Nominal	1.5D	Case 5	103	531.02			0.0000	10.99	10.42	10.80	11.08	
54	Nominal	1.5D	Case 5	104	530.47			.0000	10.99	1.70	1.77	1.75	
54	Nominal	1.5D	Case 5	105	529.56			.0760	10.99	1.47	1.51	1.76	
54	Nominal	1.5D	Case 5	106	529.54			.1560	10.99	1.12	1.29	1.78	
54	Nominal	1.5D	Case 5	107	529.53			.2330	10.99	0.83	1.01	1.80	
54	Nominal	1.5D	Case 5	108	529.64			.3021	10.99	0.65	0.78	1.84	
54	Nominal	1.5D	Case 5	109	529.77			.3405	10.99	0.60	0.72	1.81	
54	Nominal	1.5D	Case 5	110	529.91			.3728	10.99	0.64	0.77	1.69	
54	Nominal	1.5D	Case 5	111	530.08			.4136	10.99	0.69	0.82	1.77	
54	Nominal	1.5D	Case 5	112	530.36			.4550	10.99	0.73	0.87	1.78	
54	Nominal	1.5D	Case 5	113	530.54			.5218	10.99	0.79	0.95	1.77	
54	Nominal	1.5D	Case 5	114	530.67			.6017	10.99	0.85	1.04	1.83	
54	Nominal	1.5D	Case 5	115	530.77			.5199	10.99	0.79	0.94	1.77	
54	Nominal	1.5D	Case 5	116	530.79			.4586	10.99	0.73	0.88	1.78	
54	Nominal	1.5D	Case 5	117	530.74			.4208	10.99	0.69	0.83	1.78	
54	Nominal	1.5D	Case 5	118	530.76			.3764	10.99	0.64	0.77	1.77	
54	Nominal	1.5D	Case 5	119	530.82			.3419	10.99	0.60	0.72	1.79	
54	Nominal	1.5D	Case 5	120	530.81			.3048	10.99	0.61	0.73	1.79	
54	Nominal	1.5D	Case 5	121	530.82			.2386	10.99	0.79	0.95	1.78	
54	Nominal	1.5D	Case 5	122	530.87			.1595	10.99	1.09	1.28	1.77	
54	Nominal	1.5D	Case 5	123	530.90			.0000	10.99	1.46	1.52	1.78	
54	Nominal	1.5D	Case 5	124	530.95			.0000	10.99	1.70	1.79	1.75	

ESCORT RDG	PMFPUP	PMFPDN	PSTALTEX	PAMB	PTSB1	PTSB2	PTSBNORM	Nozzle area correction	Corrected PTSBNORM	PSTCNORM	MDOTSF
103	10.93	10.81	1.74	14.31	14.30	14.31	1.29	1.13	1.46	0.958	0.0699
104	1.75	1.75	1.75	14.31	1.73	1.73	0.99	1.13	1.12	.995	.0699
105	1.76	1.76	1.76	14.31	20.17	20.15	11.43	1.13	12.92	.846	.0699
106	1.78	1.76	1.77	14.31	41.30	41.25	23.24	1.13	26.26	.679	.0699
107	1.81	1.78	1.78	14.31	61.73	61.66	34.20	1.13	38.85	.510	.0699
108	1.85	1.81	1.81	14.31	80.07	79.99	43.50	1.13	49.15	.389	.0699
109	1.83	1.78	1.78	14.31	89.98	89.88	49.69	1.13	56.15	.364	.0699
110	1.73	1.67	1.67	14.31	98.57	98.46	58.25	1.13	65.82	.416	.0699
111	1.82	1.75	1.74	14.31	109.67	109.57	62.00	1.13	70.07	.427	.0699
112	1.85	1.77	1.76	14.31	120.71	120.60	67.85	1.13	76.67	.449	.0699
113	1.88	1.78	1.77	14.31	138.42	138.30	78.15	1.13	88.31	.490	.0699
114	1.92	1.79	1.78	14.31	159.48	159.33	87.27	1.13	98.62	.519	.0699
115	1.88	1.78	1.78	14.31	138.08	137.95	77.89	1.13	88.02	.489	.0699
116	1.85	1.77	1.76	14.31	121.68	121.56	68.50	1.13	77.40	.452	.0699
117	1.83	1.76	1.76	14.31	111.64	111.52	62.67	1.13	70.82	.428	.0699
118	1.81	1.75	1.75	14.31	99.83	99.75	56.53	1.13	63.87	.401	.0699
119	1.81	1.76	1.76	14.31	90.58	90.49	50.67	1.13	57.25	.370	.0699
120	1.0	1.76	1.76	14.31	80.89	80.80	45.23	1.13	51.11	.373	.0699
121	1.78	1.75	1.76	14.31	63.50	63.42	35.64	1.13	40.27	.488	.0699
122	1.77	1.75	1.76	14.31	42.30	42.25	23.92	1.13	27.03	.671	.0699
123	1.76	1.75	1.76	14.31	20.67	20.65	11.73	1.13	13.25	.846	.0699
124	1.75	1.75	1.75	14.31	1.76	1.75	1.00	1.13	1.13	.998	.0699

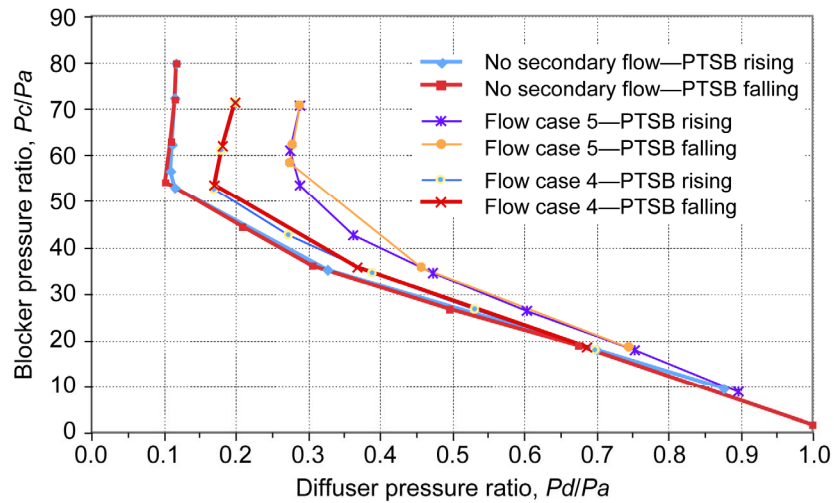


Figure 25.—Annular nozzle, length/diameter = 1.5, nominal position (total pressure blocker supply (PTSB)).

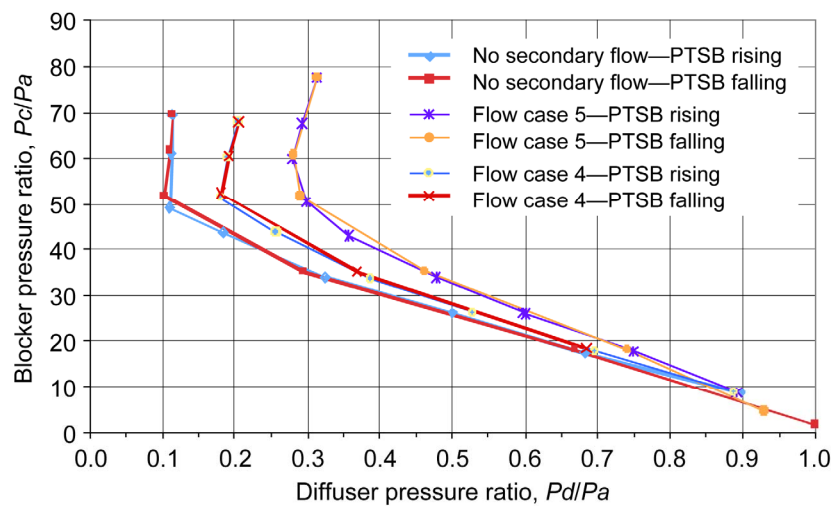


Figure 26.—Annular nozzle, length/diameter = 1.5, nominal 1-in. position (total pressure blocker supply (PTSB)).

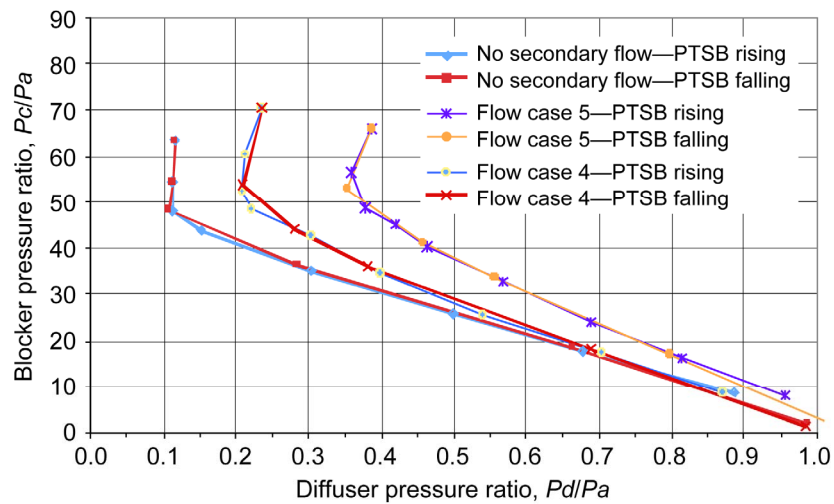


Figure 27.—Annular nozzle, length/diameter = 1.5, nominal 2-in. position (total pressure blocker supply (PTSB)).

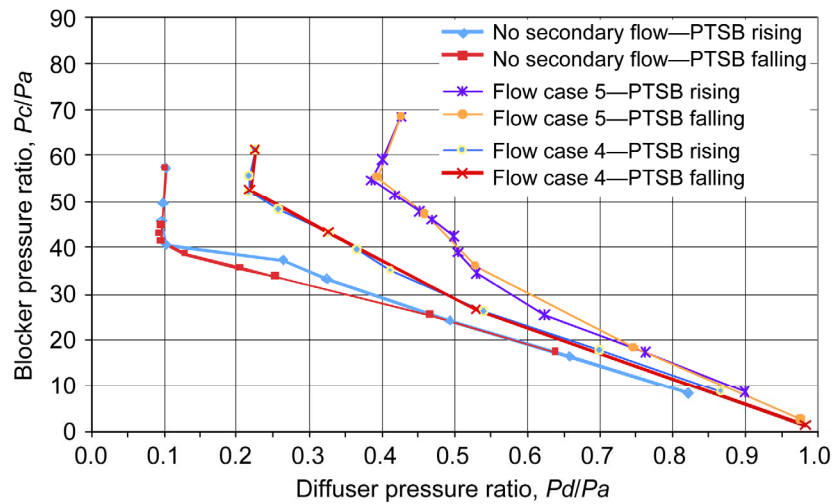


Figure 28.—Annular nozzle, length/diameter = 1.5, nominal 3-in. position (total pressure blocker supply (PTSB)).

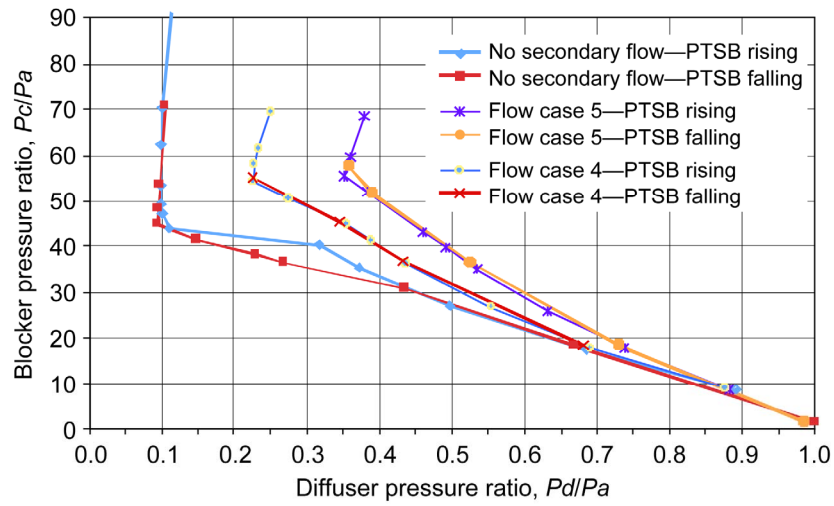


Figure 29.—Annular nozzle, length/diameter = 1.5, nominal 4-in. position (total pressure blocker supply (PTSB)).

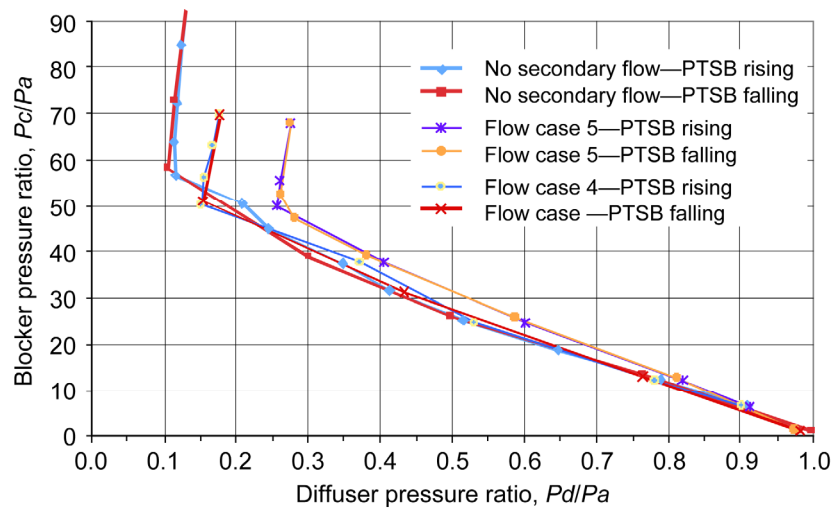


Figure 30.—Discrete axial nozzle, length/diameter = 1.5, nominal position (total pressure blocker supply (PTSB)).

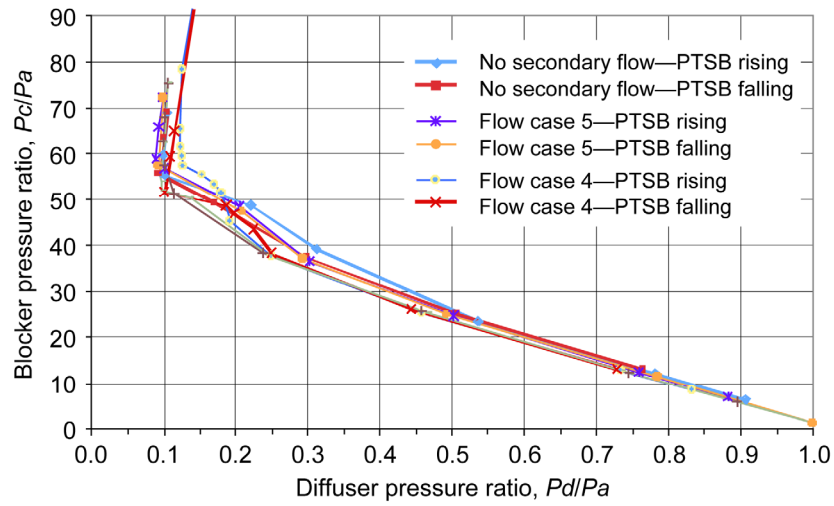


Figure 31.—Discrete axial nozzle, length/diameter = 1.5, no secondary flow (total pressure blocker supply (PTSB)).

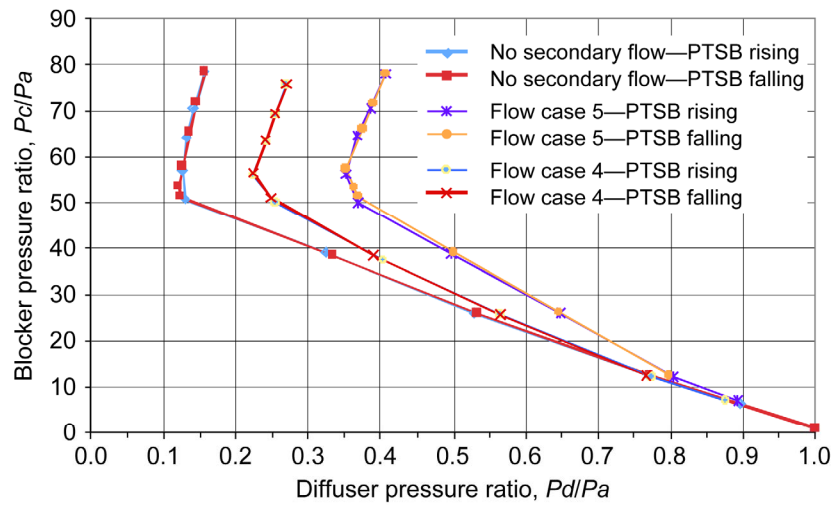


Figure 32.—Scarfed nozzle, length/diameter = 1.5, nominal 3.78-in. position (total pressure blocker supply (PTSB)).

References

1. Kastner Jr., C.E., "Preliminary Design of a CB Diffuser/Steam Blocker (Configuration 2) To operate the J-2X engine in Test Stand B-2," internal report for PBOSG and NASA Glenn Research Center Plum Brook Station, August 28, 2006
2. Weaver, H., Dickens, K., and Edwards, D., "Steam Blocker-Diffuser Integration Scale Model Test Plan," May 29, 2007.
3. Hale, James W., "Comparison of Diffuser-Ejector Performance with Five Different Driving Fluids" AEDC-TDR-63-207, Arnold Engineering Development Center, October 1963.
4. "The Standards for Steam Jet Vacuum Systems," published by "The Heat Exchange Institute."

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14. ABSTRACT The center-body diffuser (CBD) steam blocker (SB) system is a concept that incorporates a set of secondary drive nozzles into the envelope of a CBD, such that both nozzle systems (i.e., the rocket engine and the steam blocking nozzles) utilize the same supersonic diffuser, and will operate either singularly or concurrently. In this manner, the SB performs as an exhaust system stage when the rocket engine is not operating, and virtually eliminates discharge flow on rocket engine shutdown. A 2.25-percent scale model of a proposed SB integrated into a diffuser for the Plum Brook B-2 facility was constructed and cold-flow tested for the purpose of evaluating performance characteristics of various design options. These specific design options addressed secondary drive nozzle design (method of steam injection), secondary drive nozzle location relative to CBD throat, and center-body throat length to diameter (L/D) ratios. The objective of the test program is to identify the desired configuration to carry forward should the next phase of design proceed. The tested scale model can provide data for various pressure ratios; however, its design is based on a proposed B-2 spray chamber (SC) operating pressure of 4.0 psia and a steam supply pressure of 165 psia.					
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